Helsinki Studies in Education, number 106
Kasvatustieteellisiä tutkimuksia, numero 106

Marja Eliisa Holm

Executive functions and achievement emotions among adolescents

Mathematics difficulties, low mathematics performance, and special education support in mathematics

Doctoral dissertation, to be presented for public discussion with the permission of the Faculty of Educational Sciences of the University of Helsinki, in room 302, Athena, Siltavuorenpenger 3A, on the 8th of January, 2021 at 12 o'clock.

Helsinki 2020

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Yliopistopaino Unigrafia, Helsinki

ISBN 978-951-51-6911-2 (paperpack)
ISBN 978-951-51-6912-9 (PDF)

ISSN 1798-8322 (paperpack)
ISSN 2489-2297 (PDF)

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Abstract
Mathematics learning should be viewed in behavioral and emotional levels. Adolescents might have problems directing, controlling and coordinating their behaviors, such as directing attention and planning tasks in advance. Such executive function (EF) problems might relate to mathematics learning. Adolescents might also experience enjoyment, pride, anger, anxiety, shame, hopelessness, and boredom in mathematics learning. Thus, such mathematics-related achievement emotions and EF problems among adolescents with mathematics difficulties and low mathematics performance should be investigated. Classroom mechanisms, such as teacher support, could relate to achievement emotions. So, it is important to investigate whether special education support is associated with adolescents' achievement emotions. Such investigation will help generate support for adolescents' mathematics learning.

The three studies (I–III) constructing the current dissertation examined adolescents' EF problems and mathematics-related achievement emotions. Study I examined EF problems, and study II examined emotions among adolescents with mathematics difficulties (the weakest 10%), low mathematics performance (low level 10–25%), and average or higher mathematics scores. Study III investigated relationships between special education support and emotions when controlling for mathematics performance, gender, and class size. Specifically, study III investigated emotions among adolescents receiving special education support in special education (self-contained) and in general mathematics classrooms. Study III also investigated whether the proportion of adolescents receiving special education support in general mathematics classrooms is associated with the emotions of those receiving no special education support. In study I, a teacher rating inventory was used to assess adolescents' EF problems with distractibility, impulsivity, hyperactivity, directing attention, sustaining attention, shifting attention, initiative, planning, execution, and evaluation. In studies I and II, a student-reported questionnaire was used to assess mathematics-related enjoyment, pride, anger, anxiety, shame, hopelessness, and boredom.

The results showed that adolescents with mathematics difficulties had more problems with several EFs and reported to experience less positive and more negative emotions than those with average or higher scores. However, the differences in hyperactivity, impulsivity, and boredom were not significant. Those with mathematics difficulties had even more problems with several EFs and reported more shame than those with low mathematics performance. Adolescents with low mathematics performance only had shifting attention problems but reported less positive and more negative emotions than those with average or higher scores. These results revealed that various EF problems, excluding hyperactivity and impulsivity, are typical of those with mathematics difficulties, while negative emotions were characteristic of both adolescents with mathematics difficulties and those with low mathematics performance.

The results also showed that both females and males with mathematics difficulties had several EF problems, but there was gender variation in emotions across performance groups. Mainly females with mathematics difficulties reported negative emotions such as low pride and enjoyment and high hopelessness. Mainly males with low mathematics performance reported negative emotions such as high anger, anxiety, and hopelessness.

The results also showed that adolescents receiving special education support in general mathematics classrooms reported less positive and more negative emotions than those receiving special education support in self-contained classrooms. Even adolescents receiving no special education support reported more anxiety, hopelessness, and boredom when the proportion of classmates receiving special education support was higher in general classrooms.

The results suggest that both males and females with mathematics difficulties need comprehensive support for EF problems. Adolescents with mathematics difficulties and low performance also need comprehensive support for achievement emotions. In fact, the results indicated that special education support in self-contained classrooms might be a central way to support the achievement emotions of adolescents struggling with mathematics. In turn, special education support in general classrooms did not necessarily support achievement emotions. To implement inclusion (i.e., serving all students in general classrooms) educators and policymakers should develop practical solutions that support the achievement emotions of students in general classrooms.

Keywords: achievement emotions, adolescents, behavior, executive functions, inclusion, low performance, mathematics difficulties, special education support

Helsingin yliopisto, Kasvatustieteellinen tiedekunta
Kasvatustieteellisiä tutkimuksia, numero 106

Marja Eliisa Holm

Toiminnanohjaustaidot ja akateemiset tunteet nuorilla
Matematiikan vaikeudet, heikko matematiikan suoritus ja erityisopetustuki matematiikassa

Tiivistelmä

Matematiikan oppimista pitäisi tarkastella käytöksen ja tunteiden tasoilla. Nuorilla voi olla ongelmia suunnata, kontrolloida ja koordinoida käytöstään, kuten suunnata tarkkaavaisuuttaan tai suunnitella tehtäviä etukäteen. Nämä toiminnanohjauspulmat voivat liittyä matematiikan oppimiseen. Nuoret voivat myös kokea nautintoa, ylpeyttä, vihaa, ahdistusta, häpeää, toivottomuutta ja tylsyyttä matematiikan oppimisessaan. Siksi näitä matematiikkaan liittyviä akateemisia tunteita ja toiminnanohjauspulmia pitäisi tutkia nuorilla, joilla on vaikeuksia tai heikko suoritus matematiikassa. Luokan mekanismit, kuten opettajan tuki, voivat olla yhteydessä akateemisiin tunteisiin. Siksi on tärkeää tutkia, onko erityisopetustuki yhteydessä nuorten akateemisiin tunteisiin. Tämä tutkimus auttaa tukemaan nuorten matematiikan oppimista.

Tämä väitöskirja muodostuu kolmesta tutkimuksesta (I–III), jotka selvittivät nuorten toiminnanohjauspulmia ja matematiikkaan liittyviä akateemisia tunteita. Tutkimus I selvitti toiminnanohjauspulmia ja tutkimus II selvitti tunteita nuorilla, joilla on matematiikan vaikeuksia (alin 10 %), heikko suoritus matematiikassa (heikko taso 10–25 %) ja keskitasoinen tai korkeampi matematiikan suoritus. Tutkimus III selvitti erityisopetustuen ja tunteiden yhteyksiä, kun matematiikan suoritus, sukupuoli ja luokkakoko oli kontrolloitu. Tarkemmin sanoen tutkimus III selvitti tunteita nuorilla, jotka saavat matematiikan erityisopetustukea omassa erityisopetusluokassaan tai yleisopetusluokassa. Tutkimus III selvitti myös, vaikuttaako matematiikan erityisopetustukea yleisopetusluokassa saavien nuorten osuus niiden nuorten tunteisiin, jotka eivät saa tätä tukea. Tutkimuksessa I opettajan täyttämää kyselyä käytettiin, kun selvitettiin nuorten toiminnanohjauspulmia häiriöärsykkeiden kontrolloinnissa, impulsiivisuudessa, hyperaktiivisuudessa, tarkkaavuuden suuntaamisessa, tarkkaavuuden ylläpidossa, tarkkaavuuden siirtämisessä, aloitteellisuudessa, suunnittelussa, toteutuksessa ja arvioinnissa. Tutkimuksissa I ja II käytettiin itsearviointiin perustuvaa kyselyä, kun selvitettiin nuorten matematiikkaan liittyvää nautintoa, ylpeyttä, vihaa, ahdistusta, häpeää, toivottomuutta ja tylsyyttä.

Tulokset osoittivat, että nuorilla, joilla oli matematiikan vaikeuksia, oli enemmän pulmia useissa toiminnanohjaustaidoissa ja he raportoivat kokevansa

vähemmän positiivisia ja enemmän negatiivisia tunteita kuin nuoret, joilla oli keskitasoinen tai korkeampi suoritus. Kuitenkaan erot hyperaktiivisuudessa, impulsiivisuudessa ja tylsyydessä eivät olleet merkittäviä. Nuorilla, joilla oli matematiikan vaikeuksia, oli jopa enemmän pulmia useissa toiminnanohjaustaidoissa, ja he raportoivat kokevansa enemmän häpeää kuin nuoret, joilla oli heikko suoritus. Lisäksi nuorilla, joilla oli heikko matematiikan suoritus, oli enemmän tarkkaavuuden siirtämisen pulmia, mutta he raportoivat kokevansa vähemmän positiivisia ja enemmän negatiivisia tunteita kuin nuoret, joilla oli keskitasoinen tai korkeampi suoritus. Nämä tulokset osoittavat, että useat toiminnanohjauspulmat, paitsi hyperaktiivisuus ja impulsiivisuus, ovat tyypillisiä nuorille, joilla on matematiikan vaikeuksia. Toisaalta negatiiviset tunteet olivat ominaisia oppilaille, joilla oli vaikeuksia sekä heikko suoritus matematiikassa.

Tulokset osoittivat myös, että sekä tytöillä ja pojilla, joilla oli matematiikan vaikeuksia, oli useita toiminnanohjauspulmia. Kuitenkin tunteissa oli sukupuolen vaihtelua matematiikan ryhmien välillä. Erityisesti tytöt, joilla oli matematiikan vaikeuksia, raportoivat kokevansa negatiivisia tunteita, kuten vähäistä ylpeyttä ja nautintoa sekä toivottomuutta. Erityisesti pojat, joilla oli heikko matematiikan suoritus, raportoivat kokevansa negatiivisia tunteita, kuten vihaa, ahdistusta ja toivottomuutta.

Tulokset osoittivat myös, että nuoret, jotka saavat matematiikan erityisopetustukea yleisopetusluokassa, raportoivat kokevansa vähemmän positiivisia tunteita ja enemmän negatiivia tunteita kuin nuoret, jotka saivat erityisopetustukea omassa erityisopetusluokassaan. Jopa nuoret, jotka eivät saa erityisopetustukea, raportoivat kokevansa enemmän ahdistusta, toivottomuutta ja tylsyyttä yleisopetusluokassa, jossa erityisopetustukea saavien nuorten osuus oli suurempi.

Tulokset ehdottavat, että pojat ja tytöt, joilla on matematiikan vaikeuksia, tarvitsevat kokonaisvaltaista tukea toiminnanohjauspulmiinsa. Lisäksi nuoret, joilla on matematiikan vaikeuksia ja heikko suoritus matematiikassa, tarvitsevat kokonaisvaltaista tukea tunteisiinsa. Itse asiassa tulokset ehdottavat, että erityisopetustuki omassa erityisopetusluokassa saattaa olla keskeinen keino tukea niiden nuorten tunteita, joille matematiikan oppiminen on vaikeaa. Toisaalta tulokset ehdottavat, että erityisopetustuki yleisopetusluokassa ei välttämättä tue tunteita. Kun inkluusiota toteutetaan, eli tuetaan kaikkia oppilaita yleisopetusluokassa, kouluttajien ja päättäjien pitäisi kehittää käytännön ratkaisuja oppilaiden tunteiden tukemiseksi yleisopetusluokassa.

Avainsanat: akateemiset tunteet, nuoret, käytös, toiminnanohjaustaidot, inkluusio, heikko suoritus, matematiikan vaikeudet, erityisopetustuki

Acknowledgements

The dissertation process—my learning and research journey—would not have been successful without the support of several people. I would like to thank my supervisors, Professor Markku Hannula and Docent Anu Laine. I am particularly grateful to Markku, who has consistently guided and encouraged me during the dissertation process. Markku always believed in me even when I occasionally lost faith in what I was doing. Markku has guided me with his expertise, and his feedback on my work has always been critical and thought provoking, helping me to fully develop as a researcher. Anu has also supported me during my dissertation. She has encouraged me to keep moving forward and to have faith in what I do. She guided me with her expertise and gave me the freedom to make my own choices while justifying them. This has helped me develop as a researcher. I am very grateful that I had such great supervisors who have both become close to me.

I would also like to thank the pre-examiners of my dissertation, Professor Maria Passolunghi and Professor Erno Lehtinen, for providing expert feedback that helped me finalize my work. I am grateful that I had the opportunity to have Professor Mikko Aro as an opponent.

I thank the other researchers who were involved in the dissertation process: Associate Professor Johan Korhonen, Professor Piia Björn, Professor Pirjo Aunio, and Dr. Liisa Klenberg. Thank you for reading and commenting on the research articles and giving expert feedback on the work. Your guidance has helped me develop as a researcher during this journey. I would also like to thank Professor Patrik Scheinin and Johan for helping me prepare for my public defense. I likewise thank Professor Reinhard Pekrun for his professional assistance in measuring and determining achievement emotions.

I also want to express my gratitude to the Finnish Cultural Foundation for supporting the dissertation project financially.

Finally, I thank my supportive and loving family. I am truly grateful to my parents, Riitta and Matti. They have supported me and cared for my children during my absence. In addition, I owe my gratitude to my in-laws, Sirkka and Jorma, who looked after my children during the critical phases of this dissertation. I am most sincerely grateful to my husband, Tuomas, who has encouraged me all this time. Finally, I want to thank my wonderful and dear children, Silja and Lilja. They have brought color to my life and inspired me every day, counterbalancing the rigors of the dissertation process.

Helsinki, 13.11.2020
Marja Eliisa Holm

Contents

List of original articles

This dissertation is based on the following three original publications, which are referred to in the text by their Roman numerals (Studies I-III):

I: Holm, M. E., Aunio, P., Björn, P. M., Klenberg, L. Korhonen, J., & Hannula, M. S. (2018). Behavioral executive functions among adolescents with mathematics difficulties. *Journal of Learning Disabilities, 51*, 578–588. https://doi.org/10.1177/0022219417720684

II: Holm, M. E., Hannula, M. S., & Björn, P. M. (2017). Mathematics-related emotions among Finnish adolescents across different performance levels. *Educational Psychology, 37*, 205–218. https://doi.org/10.1080/01443410.2016.1152354

III: Holm, M. E., Björn, P. M., Laine, A., Korhonen, J., & Hannula, M. S. (2020). Achievement emotions among adolescents receiving special education support in mathematics. *Learning and Individual Differences, 79*. Advance online publication. https://doi.org/10.1016/j.lindif.2020.101851

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1 Introduction

Mathematics is difficult for some students. These difficulties have been studied at various levels: cognitive, behavioral, social, and emotional (Geary, Hoard, Nugent, & Byrd-Craven, 2008; Passolunghi, 2011; Wu, Willcutt, Escovar, & Menon, 2014). This study investigated executive function (EF) problems and emotions behind students' mathematics difficulties.

EFs regulate and control students' behaviors in the service of purposive actions (Jurado & Rosselli, 2007; Miyake & Friedman, 2012). EFs include components, such as attention, hyperactivity, impulsivity, planning, initiative, and evaluation (Klenberg, Jämsä, Häyrinen, Lahti-Nuuttila, & Korkman, 2010). Adolescents with EF problems might be unable to shift their attention from one activity to another or wait for their turn (impulsivity). EFs might thus play an important role in their mathematics learning (Bull & Devine, 2014). Adolescents might also experience various mathematics-related achievement emotions, including anxiety, hopelessness, shame, boredom, anger, enjoyment, or pride in mathematics classroom, learning, and testing situations (Pekrun, 2006). Such emotions are worth investigating because they guide adolescents' learning and affect their well-being (Pekrun, 2017).

Adolescents who are at critical stages of their schooling and at risk of dropping out and academic failure and who undergo fundamental changes in emotions and behavioral problems (Eccles, 1999) require their emotions and EFs to be understood and supported. Adolescents struggling with mathematics might be a risk of dropping out of school (Hakkarainen, Holopainen, & Savolainen, 2015). As negative achievement emotions and EF problems might increase the risk of dropping out and failure (Fitzpatrick, Archambault, Janosz, & Pagani, 2015; Respondek, Seufert, Stupnisky, & Nett, 2017), supporting adolescents' EF problems and achievement emotions might decrease this risk. Investigating EF problems and mathematics-related achievement emotions of adolescents struggling with mathematics might help teachers to generate teaching methods and support for these youth.

However, EF problems and such emotions are not comprehensively understood among adolescents struggling with mathematics. Previous studies have also suggested that the characteristics of students with mathematics difficulties (i.e., difficulties with basic mathematics and underlying competencies) should be compared to those with low mathematics performance (i.e., problems in more demanding mathematics) and with average or higher mathematics scores (e.g., Mazzocco, 2008). These comparative studies might reveal the specific problems of students with mathematics difficulties. For example, previous studies found that students with mathematics difficulties have more problems with working memory (i.e., the ability to hold and process information) than those with low mathematics performance and average or higher scores. In turn, students with low mathematics performance did not necessarily have these problems (Geary et al., 2008). As EFs and mathematics-related achievement emotions are associated with students' mathematics performance (Clark, Pritchard, & Woodward, 2010; Pekrun, Lichtenfeld, Marsh, Murayama, & Goetz, 2017), these two components are important to study in the research field of mathematics difficulties.

Previous studies indicated that males have more EF problems and females reported more negative mathematics-related achievement emotions (Frenzel, Pekrun, & Goetz, 2007a; Klenberg et al., 2010). However, it is not understood whether these issues also occur among adolescents with mathematics difficulties and low mathematics performance. To provide comprehensive support to adolescents struggling with mathematics, it is also important to investigate whether there is gender variation in EF problems and emotions across groups with mathematics difficulties and with low mathematics performance.

Adolescents with mathematics difficulties and low mathematics performance might receive special education support in general or through self-contained mathematics classrooms (Finnish National Board of Education [FNBE], 2004, 2016). From political and educational perspectives, there is a worldwide movement toward inclusion, through which students requiring special education support are served in general classrooms (United Nations Educational, Scientific and Cultural Organization [UNESCO], 2009b, 2017). However, some studies suggest this inclusion does not necessarily support students' affective outcomes. Specifically, previous studies have suggested that special education support in general classrooms might relate negatively to students' affective outcomes—enjoyment and self-concept—while this relationship might be positive in self-contained classrooms (Kocaj, Kuhl, Jansen, Pant, & Stanat, 2018; Szumski & Karwowski, 2015). So, it is also important to investigate whether this relationship exists for various mathematics-related achievement emotions. Investigating emotions among adolescents struggling with mathematics in general and in self-contained classrooms can help educators understand and support these students' mathematics performance in such settings.

The learning of adolescents receiving no special education support might be disturbed in general classrooms when the proportion of classmates receiving special education support is higher. For example, the presence of students receiving special education support in general classrooms might reduce teachers' support (Dyson, Farrell, Polat, Hutcheson, & Gallannaugh, 2004) and the learning demands (Ruijs, Van der Veen, & Peetsma, 2010) of those receiving no special education support. Because support and learning demands might be related to achievement emotions (Pekrun, 2006), adolescents receiving no special education support might experience negative mathematics-related achievement emotions in more inclusive classrooms—containing more students receiving special education support.

Thus, the present study investigates differences in EF problems and mathematics-related achievement emotions among adolescents with mathematics difficulties, low mathematics performance, and average or higher mathematics scores and also investigates the gender differences in these relationships. This study also investigates the mathematics-related achievement emotions among adolescents receiving special education support in self-contained and in general classrooms. Finally, this work examines whether higher proportions of adolescents receiving special education support in general classrooms relate to the mathematics-related achievement emotions of those receiving no special education support. This current investigation will help teachers generate support for adolescents' mathematics learning from the perspective of EFs and emotions. This investigation also provides a basis for future research on EFs and emotions, and it will open a new perspective on the theory of EFs, achievement emotions, and special education support.

2 Theoretical background

Mathematics difficulties refers to difficulties in basic mathematics and underlying procedural and conceptual competencies, such as understanding arithmetic concepts (Geary, 2004). Several components, such as working memory, attitude to mathematics, anxiety, and attention problems, might be associated with mathematics difficulties (Geary, 2004; Kaufmann & von Aster, 2012; Mazzocco & Räsänen, 2013). However, various EFs and achievement emotions are also significant components in mathematics performance (Bull & Lee, 2014; Pekrun, 2006). Hence, this study investigates these components among adolescents with mathematics difficulties and low mathematics performance. Additionally, these adolescents struggling with mathematics might receive special education support in self-contained and general classroom settings, and this support might relate to their achievement emotions (Pekrun, 2006).

In sections 2.1 to 2.5 the components of the theoretical framework for this study are defined and discussed: mathematics difficulties and low mathematics performance, EFs, achievement emotions, and special education support. In Section 2.6 this theoretical framework is summarized.

2.1 Mathematics difficulties and low mathematics performance

Mathematics difficulties refers to various difficulties in basic mathematics, such as difficulties in calculation, using efficient counting strategies, approximating numbers, understanding mathematics concepts, understanding magnitude, and solving basic multi-digit computation, and word problems (Geary, 2004; Mazzocco, Devlin, & McKenney, 2008; Powell, Fuchs, & Fuchs, 2013).

In the present dissertation, Geary's (2004) hierarchical framework (Figure 1) was used to define mathematics performance and difficulties. In this framework, performance in any given domain of mathematics (e.g., fraction calculations) will depend on a conceptual understanding of the domain (e.g., understanding the fraction concept) and procedural knowledge (e.g., understanding rules) that supports mathematics performance. Mathematics difficulties can be considered to be difficulties in conceptual and procedural competencies within one or several domains (Geary, 2004), such as arithmetic and word problem solving. For example, students with mathematics difficulties might have a poor conceptual understanding of counting principles and hence may commit more counting errors and use an incorrect counting procedure when solving mathematical problems. And as mentioned earlier, there might be other problems (e.g., cognitive deficits) behind mathematics difficulties (Geary, 2004; Kaufmann & von Aster, 2012; Kyttälä, 2008; Mazzocco, 2008).

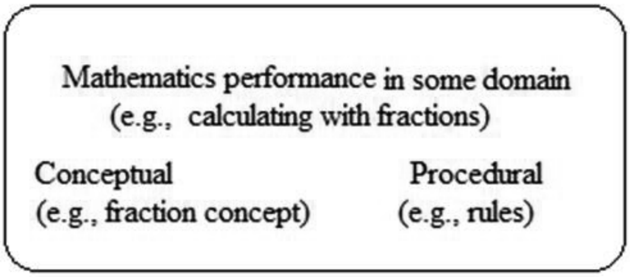

Figure 1. Mathematics performance.

Previous studies have identified mathematics difficulties among adolescents of a similar nature (Mazzocco & Devlin, 2008; Mazzocco et al., 2008; Mazzocco, Feigenson, & Halberda, 2011; Mazzocco, Myers, Lewis, Hanich, & Murphy, 2013). These studies indicated that adolescents with mathematics difficulties make more mistakes in easy arithmetic tasks and have a lower conceptual understanding of arithmetic operations and rational numbers (e.g., decimals, and fractions), use fewer automated arithmetic procedures (e.g., more finger counting), and have more problems approximating numbers (e.g., judging which array of items is more numerous or how many items are present) than those with low mathematics performance and average or higher mathematics scores. On the other hand, adolescents with low mathematics performance did not have these problems in basic mathematics and made more but similar errors (in hard tasks) than those with average or higher mathematics scores.

In summary, these studies suggest that adolescents with mathematics difficulties have more substantial problems in basic mathematics and underlying procedural and conceptual competencies than those with low mathematics performance. Hence, previous studies argue that it is critical to differentiate students with mathematics difficulties from those with low mathematics performance (Mazzocco, 2008).

The literature used different terminology, such as mathematical disability, developmental dyscalculia, mathematical learning difficulties, and mathematics difficulties, to describe mathematics-related difficulties (Mazzocco, 2007; Murphy, Mazzocco, Hanich, & Early, 2007). The present dissertation used the term mathematics difficulties because its identification is based on mathematics test performance (Kaufmann & von Aster, 2012). Dyscalculia refers to difficulties in basic calculations which can be tracked to the neural level and the determination of which should be based on a diagnostic evaluation (Kaufmann & von Aster, 2012). The prevalence of dyscalculia is estimated to be 3% to 6% of school-age children (Kaufmann & von Aster, 2012; Rubinsten & Henik, 2009). No systematic statistics can be found in Finland, because Finnish special education is not based on diagnosing learning difficulties. Rather, special education support in Finland is provided to those who need it (Björn, Aro, Koponen, Fuchs, & Fuchs, 2016; FNBE, 2004, 2016).

Furthermore, measures specifically designed to diagnose mathematics difficulties are not available (Geary, 2004; Murphy et al., 2007). Indeed, most researchers rely on standardized performance tests, sometimes combined with measures of intelligence (Geary, 2004; Mazzocco, 2008). Notably, the cutoff values on the standardized tests used in different studies vary greatly, ranging from the 5th to the 45th percentile (see Murphy et al., 2007). However, an increasing amount of research suggests that scoring below the 11th percentile on a standardized mathematics test indicates mathematics difficulties, while scoring between the 11th and 25th percentiles indicates low mathematics performance (Geary et al., 2008; Mazzocco, 2008; Mazzocco & Devlin, 2008; Wong, Ho, & Tang, 2017; Wu et al., 2014). Scoring above the 25th percentile indicates average or higher scores (i.e., typical performers). Hence, these criteria were used in the present study to define mathematics difficulties and low mathematics performance. These criteria are summarized in Table 1.

Table 1. Mathematics performance groups.

Math difficulties	**Low math performance**	**Average or higher math scores**
Scores below the 11th percentile on a standardized mathematics test.	Scores between the 11th and 25th percentiles on a standardized mathematics test.	Scores above the 25th percentile on a standardized mathematics test.

2.2 Executive functions and their theoretical relation to mathematics performance

Students might have EF problems, for example problems with inhibiting irrelevant information, staying seated, focusing on task, switching to more appropriate task strategies, starting tasks without help, and planning a task in advance (Bull & Devine, 2014; Klenberg et al, 2010). One would assume that these EF problems would influence students' mathematics performance. The next section presents EF as a concept, measures of EF, and relationship between EFs and mathematics performance.

2.2.1 Executive functions as a concept

EFs refer to a set of higher-order processes that aid self-regulation—of cognition, of emotion, and of behavior—in the service of goal-directed actions (Hofmann, Schmeichel, & Baddeley, 2012; Jurado & Rosselli, 2007; Miyake &

Friedman, 2012). Miyake and Friedman (2012) defined EFs as a set of general-purpose control mechanisms that regulate cognition and actions.

It is agreed that EFs consist of several components, including working memory, attention functions, inhibition, and goal-directed behaviors (Garcia-Barrera, Kamphaus, & Bandalos, 2011; Gioia & Isquith, 2004; Hofmann et al., 2012; Miyake & Friedman, 2012). A dominant model of EF, proposed by Miyake et al. (2000), focused on three aspects of EF: switching, inhibition, and working memory (see also Diamond, 2013). As EFs at the behavioral level have been measured in the present study (see Section 2.2.2), there has been no investigation of working memory—the ability to hold and process information in the mind. Table 2 summarizes the concept of EFs in relation to the present study, and next, they are described.

Table 2. Executive functions.

Executive functions		
Inhibition	**Attention functions**	**Goal-directed actions**
Impulsivity	Directing attention	Initiative
Hyperactivity	Sustaining attention	Planning
Distractibility	Shifting attention	Execution of action
		Evaluation

Researchers have stated that inhibition is the primary EF (Barkley, 1997; Hofmann et al., 2012; Miyake & Friedman, 2012). Barkley (1997) defined three processes of behavioral inhibition: inhibiting prepotent responses and impulses refers to impulsivity, stopping an ongoing response refers to hyperactivity, and controlling interference refers to distractibility. For example, students with inhibition problems might be unable to wait their turn (i.e., impulsivity), be unable to stay seated (i.e., hyperactivity), and be interrupted by external stimuli (i.e., distractibility; Klenberg et al., 2010). Students with impulsivity might also have problems waiting for delayed rewards (Nigg, 2017).

Researchers have also stated that attention functions are important EF components (Garcia-Barrera et al., 2011; Gioia & Isquith, 2004; Mirsky, Pascualvaca, Duncan, & French, 1999). They have determined that attention functions include three components: directing attention to a certain stimulus, sustaining attention for an extended period, and shifting attention from one aspect of a stimulus to another (Garcia-Barrera et al., 2011; Mirsky et al., 1999). Especially, shifting attention (i.e., task-switching; shifting) is often identified as a primary component of EFs (Hofmann et al., 2012; Miyake & Friedman, 2012). Students with attention problems might have problems focusing on instruction (i.e., directing attention), working for a long period (i.e., sustaining attention), or shifting their attention from one activity to another (i.e., shifting attention; Klenberg et al., 2010).

EFs also include the self-directed actions needed for more complex goal-directed actions, such as initiation, planning, execution, and the evaluation of actions (Garcia-Barrera et al., 2011; Gioia & Isquith, 2004; Jurado et al., 2007). Individuals who have problems with goal-directed actions might have problems beginning work without help (i.e., initiative), planning their actions in advance (i.e., planning), performing activities efficiently (i.e., execution of action), or judging their own performance (i.e., evaluation; Klenberg et al., 2010).

Notably, researchers have also indicated that EFs might develop sequentially with age. The components of EF might demonstrate different developmental trajectories (Anderson, 2002; Klenberg, Korman, & Lahti-Nuuttila, 2001). Most inhibition and attention skills are developed substantially during infancy and early childhood (between 1 and 7 years of age). More complex EFs, such as shifting attention and goal-directed behaviors, are developed in later childhood (about 3 to 10 years) and are relatively mature by 12 years of age, although they continue developing into adolescence (Anderson, 2002). These complex EFs might be needed in more complex mathematics problem solving (Bull & Lee, 2014), which particularly occurs in adolescents' mathematics learning.

2.2.2 Measures of executive functions

EFs can be measured at the cognitive level with cognitive tests and at the behavioral level with rating scales for behaviors (Toplak, West, & Stanovich, 2013). The term cognitive EFs is used to describe EFs measured with cognitive tests (Miyake et al., 2000) and behavioral EFs to describe EFs measured with behavioral rating scales completed by parents, teachers, or students (Garcia-Barrera et al., 2011; Klenberg et al., 2010). For example, shifting attention can be measured with cognitive tasks that require the ability to shift between operations (e.g., number-letter task; Miyake et al., 2000) or that can be rated as behaviors in which students have difficulty changing from one type of activity to another when they are solving tasks in the classroom context (Klenberg et al., 2010).

While cognitive tests can provide reliable information about EFs in structured and non-distracting settings, behavioral rating scales are valid for measuring EFs in relation to daily living (Gioia & Isquith, 2004; Toplak et al., 2013). Therefore, rating scales completed by parents, teachers, or students (self-reporting) have been developed to analyze behavioral EFs in everyday environments, such as classrooms (Garcia-Barrera et al., 2011; Gioia & Isquith, 2004; Klenberg et al., 2010). Specifically, behavioral EFs in a mathematics classroom context were investigated in the current study. An understanding of EFs in the everyday learning environment context might help teachers to support key EFs in this context (Gioia & Isquith, 2004; Klenberg et al., 2010). Table 3 shows examples of behavioral EFs.

Table 3. Measuring behavioral executive functions (EFs).

EFs	**Behavioral EFs** Measured with behavioral rating scales
Impulsivity	Unable to wait turns
Distractibility	Is interrupted by an external distraction
Shifting attention	Has difficulties changing from one type of activity to another

2.2.2 Theoretical relation to mathematics performance

Individuals' EFs play an important role in their mathematics performance (Bull & Lee, 2014; Geary, 2004). The present study used Geary's hierarchical framework as a basis on which to define the theoretical relationship between EFs and mathematics performance. This framework states that EFs influence domain-specific mathematical competencies (i.e., conceptual and procedural competencies) and thus also mathematics performance. Hence, there are theoretical links from EFs to mathematics performance (See Figure 2).

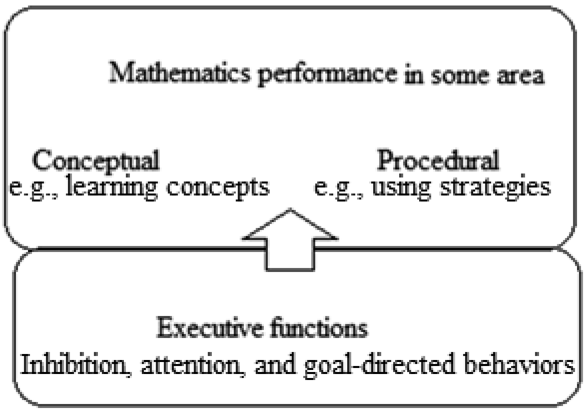

Figure 2. Theoretical relations between executive functions (EFs) and mathematics performance.

Specifically, researchers have posited that EFs might influence mathematics performance in several ways (Bull & Lee, 2014; Fuchs et al., 2006; Geary, 2004). For example, students with distractibility problems (i.e., inability to inhibit prepotent responses) might be unable to suppress inappropriate strategies (e.g., use addition when subtraction is required), might be unable to prevent irrelevant information when learning a new concept, or might use information from a word problem that is irrelevant to the solution (Bull & Lee, 2014). Students with shifting attention problems may also be unable to switch attention between mathematical operations, solution strategies, quantity ranges, or notations (e.g., between verbal digits), or between the steps of complex multistep mathematics problems (Bull & Lee, 2014).

Based on the definitions of EFs (see Section 2.2.1; Garcia- Barrera et al., 2011; Gioia & Isquith, 2004; Klenberg et al., 2010), it can be assumed that other EFs also play a key role in mathematics performance. For example, students who have problems sustaining attention might be unable to stay on task in mathematics or follow instruction with respect to a new mathematical concept. Students who have problems with initiative might be unable to start mathematics tasks independently. EFs are clearly important for mathematics performance. Thus, EF problems may also be common among students with mathematics difficulties. The present study will investigate the kinds of EF problems facing adolescents with mathematics difficulties.

2.3 Achievement emotions and their relation to mathematics performance

It is stated that several affective components, such as goals, values, beliefs, emotions, and motivation, are associated with mathematics performance and interact with each other (Hannula, 2012; Lazarus, 1991; Pekrun, 2006). For example, students who believe they are good in mathematics and whose goal is to learn mathematics might perceive that they can succeed, and that mathematics is valuable. Thus, they reported positive emotions. These positive emotions might increase their motivation (e.g., willingness to learn), and their mathematics performance might improve. In the negative cycle, students who believe they are poor in mathematics and who avoid mathematics might perceive that they cannot succeed, and that mathematics has no value for them. Thus, they report negative emotions. These negative emotions might decrease their motivation and their mathematics performance might decrease further. Because supporting adolescents' emotions might particularly improve their mathematics performance (Pekrun, 2006), this study focused on emotions.

Indeed, several theories have described emotions and their relationship to learning (Fredrickson, 2001; Hascher, 2010; Pekrun, 2006; Tracy & Robins, 2004; Weiner, 2014). In the present study, the control-value theory (Pekrun, 2006; Pekrun, Frenzel, Goetz, & Perry, 2007) was used to determine mathematics-related achievement emotions, as this theory covers multiple achievement emotions—enjoyment, pride, anger, anxiety, shame, hopelessness, and boredom—in academic learning, testing, and classroom situations. In the next two sections, the control-value theory is used to define the concept of achievement emotions and how they relate to mathematics performance.

2.3.1 Achievement emotions as a concept

The control-value theory (Pekrun, 2006; Pekrun et al., 2007) defines emotions including cognitive, motivational, expressional, physiological, and affective processes. For example, an appraisal of stressful events might cause anxiety, which leads to worry (cognitive), situation avoidance (motivation), anxious facial expressions (expressive), sweating (physiological), and anxious feelings (affective). Specifically, emotion is defined as an episode of interrelated changes in all or some of these five components in response to the evaluation of an external or internal event (see also Scherer, 2005).

The focus in this study was on seven achievement emotions—anxiety, hopelessness, shame, anger, pride, enjoyment, and boredom (see Table 4). The control-value theory (Pekrun, 2006; Pekrun et al., 2007) defines these achievement emotions as emotions tied directly to achievement outcomes or activities. Specifically, outcome-related emotions are experienced before (i.e., prospective: hopelessness, anxiety) or after (i.e., retrospective: shame, pride, anger) an academic outcome—a success or a failure. Anxiety before mathematics tasks is an example of an outcome-related emotion. On the other hand, activity-related emotions (enjoyment, anger, and boredom) are experienced in relation to academic activities. Enjoyment during homework is an example of an activity-related emotion.

Table 4. Achievement emotions.

Emotion	Object focus
Anxiety	Outcome/prospective
Hopelessness	Outcome/prospective
Shame	Outcome/retrospective
Anger	Outcome/retrospective
Pride	Outcome/retrospective
Enjoyment	Activity
Anger	Activity
Boredom	Activity

Individuals' appraisals of an external or internal event influence their emotions (e.g., Roseman, Antoniou, & Jose, 1996; Scherer, 2005). The control-value theory also states that appraisals of control and value are the central antecedent for achievement emotions (Pekrun, 2006; Pekrun et al., 2007). Specifically, students' appraisals of their own control over activities or outcomes (e.g., I will not succeed, or I caused my failure) and appraisals of the value of these activities and outcomes (e.g., this is important) affect their emotions.

In terms of outcome-related emotions, anxiety might occur if failure is uncertain (medium control). Hopelessness might arise if success is impossible and failure is certain (low control). Meanwhile, shame and pride might occur if failure or success are judged to be caused by oneself. In turn, anger might arise if failure is caused by someone or something else (e.g., poor teaching methods). If students do not care about outcomes, they will not necessarily experience outcome emotions.

In terms of activity-related emotions, enjoyment might arise if activities are controllable and positively valued (e.g., interesting). Meanwhile, anger might occur if the academic activities are perceived as being controllable but negatively valued (e.g., aversive). Boredom might arise if activities are too demanding (low control) or too easy (high control) or lack any incentive value, for example being meaningful.

The control-value theory (Pekrun, 2006; Pekrun et al., 2007) also classifies achievement emotions as typically experienced in certain situations (i.e., trait emotions) or experienced momentarily in certain situations at a certain time (i.e., state emotions). Students might experience hopelessness just before taking a math test (state). In turn, students might have the typical experience of feeling hopeless before the test (trait). Other researchers also classify emotions into trait and state emotions (e.g., Diener, 1999).

The control-value theory (Pekrun, 2006; Pekrun et al., 2007) determines that achievement emotions are organized in subject-specific ways (see also empirical evidence; Goetz, Frenzel, Pekrun, Hall, & Lüdtke, 2007). This specificity is also demonstrated in relation to mathematics difficulties (Passolunghi, 2011). Passolunghi (2011) found that students with mathematics difficulties reported anxiety in mathematics, but not in other subjects. Hence, assessments should and have been developed to measure mathematics-related achievement emotions—enjoyment, pride, anger, anxiety, shame, hopelessness, and boredom—in relation to mathematics classrooms, learning, and testing (Pekrun, Goetz, & Frenzel, 2005).

These mathematics-specific achievement emotions are shown to be important in mathematics performance and classroom learning (Frenzel, Pekrun, & Goetz, 2007b; Pekrun et al., 2017; Villavicencio & Bernardo, 2016). Hence, the present study investigated mathematics-related achievement emotions. It should also be noted that the present study investigated trait mathematic-related achievement emotions rather than state achievement emotions because the former are more stable and thus present a more permanent emotional relationship to mathematics.

2.3.2 Theoretical relation to mathematics performance

The control-value theory states that there is a reciprocal relationship between academic performance and achievement emotions (Pekrun, 2006; Pekrun et al., 2007). Other researchers also suggested that the relationship between anxiety and mathematics performance is reciprocal (Carey, Hill, Devine, & Szücs, 2016).

Specifically, the control-value theory (Pekrun, 2006; Pekrun et al., 2007) states that achievement emotions relate to academic performance, but are mediated by the processes of learning, including cognitive resources, motivation, use of strategies, and self-regulation. For example, if students experience negative emotions (e.g., anger, anxiety, and shame), their cognitive resources can be burdened, their motivation might decrease, they might be unable to self-regulate their learning, and they might use more rigid learning strategies, such as rehearsal; thus, their academic performance might decrease. In turn, if students experience positive emotions (e.g., enjoyment), they might focus more on learning tasks, their motivation might increase, their self-regulation of learning might increase, and they might use more flexible learning strategies, such as elaboration of learning material. As such, their academic performance might increase.

The control-value theory (Pekrun, 2006; Pekrun et al., 2007) also states that processes of learning and academic performance are expected to be associated with students' achievement emotions. Specifically, students' low academic performance, such as failure in a mathematics test, might reduce their perceived control and value. As defined in Section 2.3.1, students' low perceived control and value might in turn cause them to experience negative emotions. On the other hand, students' high academic performance, such as success in a mathematics test, might increase their perceived control and value; thus, they might experience positive emotions.

Figure 3 presents the reciprocal relationship between mathematics performance and mathematics-related achievement emotions. Empirical studies have also shown that this relationship in mathematics is reciprocal (Pekrun et al., 2017; Putwain, Becker, Symes, & Pekrun, 2018).

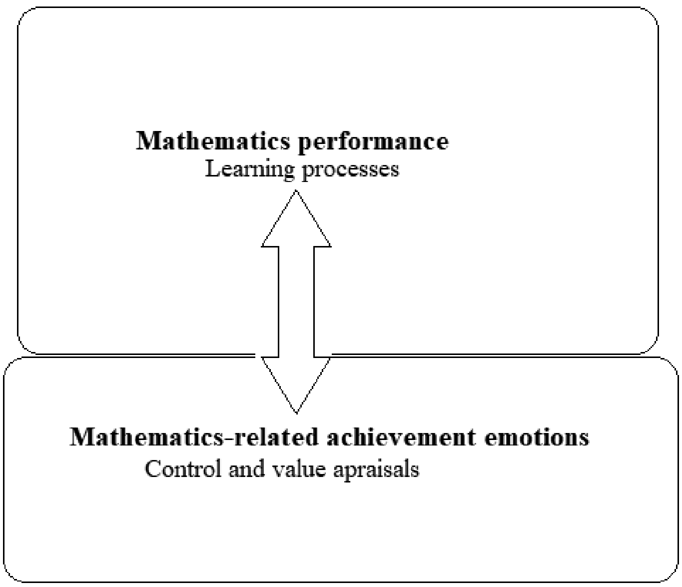

Figure 3. Theoretical relation between achievement emotions and mathematics performance.

2.4 Theoretical relationships between classroom mechanisms and achievement emotions

The control-value theory (Pekrun, 2006; Pekrun et al., 2007) also states that classroom environment mechanisms—instruction (task demands and quality), support, goal structures, expectations, feedback, and consequences—influence students' control and value appraisals and hence also students' achievement emotions.

Specifically, this theory states (Pekrun, 2006; Pekrun et al., 2007) that clearly structured, cognitively activating material and challenging task demands that match students' capabilities affect students control and value appraisals and thus emotions. Supporting environments might increase students' sense of control and their valuing of learning, and thus affected their emotions. Teachers' goal structure (e.g., individualistic or competitive), expectations (e.g., too high or low), feedback (e.g., discouraging and encouraging), and messages about the consequences of students' performance (e.g., relation to later education) might also affect students' control and value appraisals and thus their emotions. Figure 4 illustrates this relationship between classroom environment mechanisms and emotions in relation to mathematics.

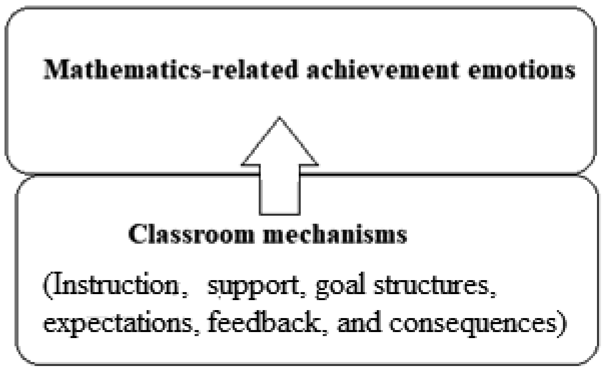

Figure 4. Theoretical relation between classroom mechanisms and achievement emotions.

Empirical evidence has also found relationships between classroom mechanisms and mathematics-related achievement emotions. This evidence indicated that teacher support, peer support, clear and structured instruction, and less competitive mathematics classrooms are associated with students' pleasant mathematics-related achievement emotions, such as increased enjoyment and reduced hopelessness, anger, and anxiety (Ahmed, Minnaert, van der Werf, & Kuyper, 2010; Frenzel et al. 2007b; Lazarides & Buchholzb, 2019; Sakiz, Pape, & Hoy, 2012).

According to the control-value theory, special education support in mathematics classrooms might also influence students' achievement emotions.

However, the control-value theory does not explicitly state that special education support is a classroom mechanism that influences achievement emotions. In the present study, this relationship is tested empirically. Special education support is defined in the next section.

2.5 Special education support in inclusive and self-contained classrooms

Students with special needs refers to students who require special education support (Bryant, Bryant, Brian, & Smith, 2019; UNESCO, 2017). Special education support (i.e., special education) means specified additional support and instruction to meet the learning needs of those with special education needs (Bryant et al., 2019; UNESCO, 2017). Special education support may be provided in different settings including general education classrooms and self-contained classrooms.

The nature of special education support services for students with special needs has changed over the past decade. At the center of this change was the Salamanca Statement at the World Conference on Special Needs Education (UNESCO, 1994). This statement explicitly endorses the idea of inclusion and the intention to form a school for all. Inclusion is based on principles such as the idea that every student has the right to education and has unique characteristics, that the diversity of students' characteristics should be taken into account when implementing education systems and educational programs, and that those with special needs must have access to general and neighborhood schools in which they have the opportunity to receive support. Finland has also committed to striving for inclusion and enhanced educational equality (Graham & Jahnukainen, 2011).

However, the concept of inclusive education (i.e., inclusion in education) has various interpretations (Bryant et al., 2019; Farrell, Dyson, Polat, Hutcheson, & Gallannaugh, 2007; Hornby, 2015; Jahnukainen, 2015; UNESCO, 2017). UNESCO (2009a) defines inclusive education as a process intended to respond to students' diversity by increasing their participation and reducing their exclusion within and from education. Although the aim of both integration and inclusion is to educate students with special needs in general classrooms, the aim and focus of inclusion is wider than the aim and focus of integration (UNESCO, 2017; UNESCO, 2009a). Specifically, integration seeks to ensure the right of students with special needs to study in general classrooms, whereas inclusion means that all learners have the right to be educated among their peers in general education. In integration, students with special needs are placed in general classroom settings with adaptions and resources, while in inclusion, the general education structure is adjusted so that everyone's learning style can be met.

Many researchers have presented the notion that inclusive education involves keeping and supporting students with special needs in general classrooms together with their peers without special needs (Farrell et al., 2007; Ruijs & Peetsma, 2009). In this study, supporting students in general classrooms is seen as part of inclusive education. The term inclusive classrooms also refers to classrooms that include both students receiving and those not receiving special education support, as opposed to general classrooms that do not include students receiving special education support (Ruijs & Peetsma, 2009).

However, some students with special needs may always be excluded from general classrooms (Hornby, 2015; Kirjavainen, Pulkkinen, & Jahnukainen, 2014). These students might receive special education support in self-contained classrooms (i.e., special classes; Bryant et al., 2019; Dixon, 2005), which does not support the idea of inclusion. A self-contained classroom is what the name implies—a self-contained classroom filled with students who have difficulties and special needs in learning (Dixon, 2005).

As the push for inclusion continues to grow (UNESCO, 2009b, 2017), it is vital to define the advantages and disadvantages of serving students in general classrooms and in self-contained classrooms. Table 5, which presents these advantages and disadvantages, will be discussed next.

Table 5. The advantages and disadvantages of serving students in general and in self-contained classrooms.

Self-contained classrooms	**Inclusive classrooms**	
Receiving SEdS	**Receiving SEdS**	**Receiving no SEdS**
Disadvantage: Fever social contacts with peers receiving no SEdS	**Advantage:** More social contacts with peers receiving no SEdS	**Advantage:** More social contacts with peers receiving SEdS
Advantage: Comparison with lower-performing peers	**Disadvantage:** Comparison with higher-performing peers	
Advantage: Teacher support and instruction	**Disadvantage:** Receiving no teacher support	**Disadvantage:** Receiving no teacher support and decreased learning demands

Note. SEdS = special education support

A typical argument put forward for inclusion is that all students have a basic human right to be educated alongside their peers in general classrooms (Hornby, 2015; Ruijs & Peetsma, 2009). Indeed, one advantage of inclusion is that students receiving special education support in general classrooms may have more social contact and friendships with their typically performing peers, and vice versa (Dixon, 2005; Hornby, 2015; Ruijs & Peetsma, 2009). In these inclusive classrooms, those receiving no special education support might even develop more accepting attitudes toward those with difficulties (Dixon, 2005; Ruijs & Peetsma, 2009). On the other hand, those receiving special education support in self-contained classrooms might have fewer social contacts and friendships with typically performing students (Dixon, 2005; Hornby, 2015).

One added disadvantage of self-contained classrooms is that students receiving special education support in such classrooms might be negatively labeled and stigmatized as those with special needs and difficulties (Dixon, 2005; Hornby, 2015). However, students receiving special education support in self-contained classrooms might be more comfortable being in the same classrooms with peers who also have difficulties (Hornby, 2015). Indeed, the big-fish-little-pond effect (BFLPE) is one important theoretical concept that should be considered.

The BFLPE indicates that a higher class-average performance has a negative effect on students' affective outcomes because students compare their performance with that of their higher-performing classmates (Marsh et al., 2008). It is possible that students receiving special education support in inclusive classrooms might compare themselves more often to higher-performing classmates (Ruijs & Peetsma, 2009), which might have a negative effect on their affective outcomes. Alternatively, students receiving special education support in self-contained classrooms might compare themselves to lower-performing classmates, which might have a positive effect on their affective outcomes.

Another advantage of self-contained classrooms might be that then students have trained special education teachers. Special education teachers are competent in providing more individualized support and instruction for students with special needs and in ensuring their optimal understanding (Dixon, 2005; Ruijs & Peetsma, 2009). Comparatively, a potential disadvantage of inclusive classrooms is the question of whether teachers who already have a classroom full of students can instruct and support those with and without special needs at the same time (Dixon, 2005). Hence, not all students in inclusive classrooms necessarily get enough teacher support. Additionally, the learning demands (e.g., challenges) of those receiving no special education support might decrease in inclusive classrooms with the presence of classmates receiving special education support (Ruijs et al., 2010).

2.5.1 Finnish special education support in mathematics

In this section, Finnish special education support in mathematics will be described. These aspects have also been described in the original article (study III). In Finland, student eligibility for special education support is often based on multi-professional evaluations, including the views of teachers, special education teachers, and parents (Björn et al., 2016; FNBE, 2004, 2016). Specifically, students in Finland receive support according to their special education support needs in mathematics rather than their diagnosis-based needs (Finnish Basic Education Act, 2010).

Notably, a new special education support framework has been implemented since our data were collected (Finnish Basic Education Act, 2010). This framework resembles the response to intervention (RTI) in the United States, divided into three tiers of support (Björn et al., 2016; FNBE, 2016). All students might receive occasional general support (Tier 1 support), such as remedial teaching (Björn et al., 2016; FNBE, 2016), which is not considered special education support. Students receive intensified support (Tier 2 support) if general support is not sufficient to meet their needs and they need more regular support in their learning. Part-time special education support is mostly considered to be Tier 2 support (Björn et al., 2016; FNBE, 2016). Students receive special support (Tier 3 support) if intensified support is not enough to meet their needs. Full-time special education support in general education classrooms or in self-contained classrooms is considered to be Tier 3 support (Björn et al., 2016; FNBE, 2004, 2016).

Students with mathematics difficulties and low mathematics performance might get special education support in general mathematics classrooms or in self-contained mathematics classrooms. In general mathematics classrooms, adolescents might receive part-time (Tier 2) or full-time (Tier 3) special education support. In self-contained mathematics classrooms, adolescents receive full-time special education support (Tier 3 support). Table 6 describes these special education support settings in mathematics, and next, these settings are described in more detail.

Table 6. Description of special education support in general and self-contained mathematics classrooms.

	Special education support in mathematics		
	In general mathematics classrooms		**In self-contained mathematics classrooms**
Levels	Part-time (Tier 2)	Full-time (Tier 3)	Full-time (Tier 3)
Description	In small groups in resource rooms for 1 or 2 hours per week with special education teachers and otherwise in general math classrooms	Integrated into general math classrooms, where special education teachers provide additional support (e.g., coteaching) for them in collaboration with math teachers	Receive full-time special education support from special education teachers in small, separate self-contained math classrooms

If general support is insufficient, students with mild difficulties in mathematics might receive part-time special education support (Tier 2) mostly in small groups in resource rooms for one or two hours per week but study otherwise in general classrooms (FNBE, 2004, 2016; Graham & Jahnukainen, 2011). These students are supported in the general education context by special education teachers, who collaborate with general mathematics teachers (FNBE, 2004, 2016). Part-time special education support seems most common in Finnish lower secondary schools (Grades 7 to 9) and is most prevalent in mathematics. In lower secondary schools, 17% of students receive part-time special education support in general, and 6% receive it in mathematics (Statistics Finland, 2011).

If part-time special education support (Tier 2) cannot meet the needs of students with more substantial mathematics difficulties, they receive full-time special education support (Tier 3) with an individualized education plan (IEP; FNBE, 2004, 2016). An IEP is a written plan for students' goals, teaching arrangements, supports, and guidance (FNBE, 2004, 2016). These students can be integrated into general mathematics classrooms, where special education teachers provide additional support to them, such as coteaching, in collaboration with mathematics teachers (FNBE, 2004, 2016). Coteaching means that the teacher and special education teacher work together on instruction, support, and classroom management (Bryant et al., 2019).

Alternatively, students with substantial mathematics difficulties might receive full-time special education support from special education teachers in small, separate self-contained mathematics classrooms (Björn et al., 2016; FNBE, 2004, 2016). In other subjects, these students are integrated into general classrooms or study in separate self-contained classrooms. About 2.7% of lower secondary school students receive full-time special education support in general classrooms, while 6% receive full-time special education support in some subjects in self-contained classrooms (Statistics Finland, 2011).

2.6 Summary of the theoretical framework

The theoretical framework of the present study, as presented above, is summarized in Figure 5. Based on the theoretical framework, students were divided into those with mathematics difficulties, low mathematics performance, and average or higher mathematics scores (Geary et al., 2008; Mazzocco, 2008). There is a link between EFs and mathematics performance (Figure 5 and *link 1*; Geary, 2004). There is a reciprocal relationship between mathematics performance and achievement emotions (*link 2*; Pekrun, 2006; Pekrun et al., 2007). Students struggling with mathematics might receive special education support in general mathematics classrooms or in self-contained classrooms (*link 3*; FNBE, 2004, 2016). Classroom mechanisms, such as instruction, support, goal structures, expectations, feedback, and consequences, are related to achievement emotions (*link 4*; Pekrun, 2006; Pekrun et al., 2007). Special education support in classroom contexts can be considered to be classroom mechanisms.

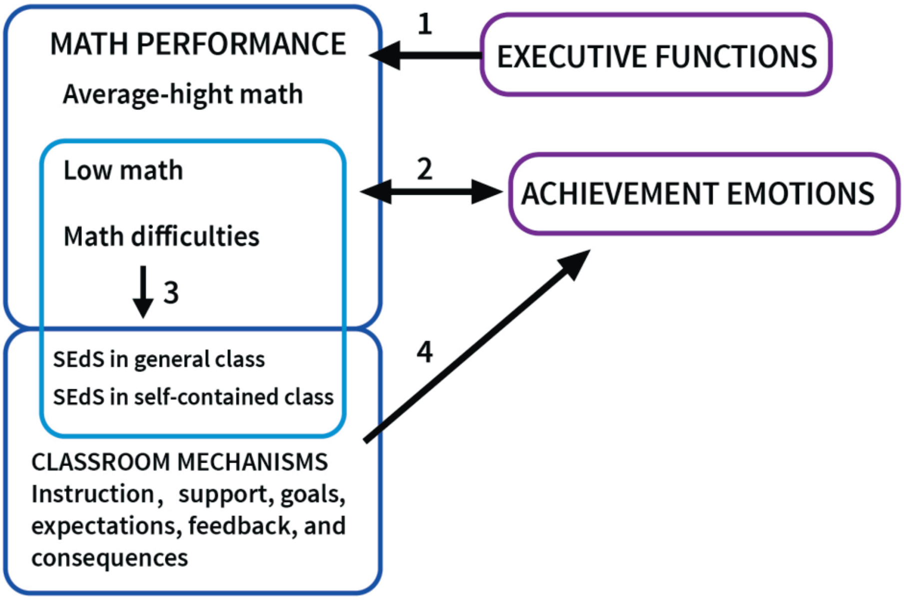

Figure 5. Summarized theoretical framework. SEdS = special education support.

3 Empirical background

Empirical findings suggested that characteristics of students with mathematics difficulties should be compared to those with low mathematics performance and average or higher mathematics scores (Geary et al., 2008; Mazzocco, 2008). These studies have shown that cognitive problems, such working memory deficits, are mainly characteristics of those with mathematics difficulties. As previous studies have also found that EFs and mathematics-related achievement emotions are related to mathematics performance (Clark et al., 2010; Pekrun et al., 2017), EF problems and such emotions among adolescents with mathematics difficulties and low mathematics performance should be investigated.

These adolescents struggling with mathematics might also receive special education support in self-contained or general mathematics classrooms. Researchers have suggested that students receiving special education support in self-contained classrooms receive more personal teacher support, while those in general classrooms are more socially integrated, that is, they interact more with their peers (Hannes, Von Arx, Christiaens, Heyvaert, & Petry, 2012; Myklebust, 2007; Ruijs & Peetsma, 2009). Because researchers have also found that personal teacher support increases enjoyment and reduces hopelessness among adolescents (Sakiz et al., 2012), adolescents receiving special education support in self-contained classrooms might report pleasant emotions.

Additionally, adolescents receiving special education support in general classrooms might compare themselves more with higher-performing classmates than those receiving special education support in lower performing self-contained classrooms. The BFLPE indicates that a higher class-average performance has a negative effect on students' affective outcomes because students compare their performance with that of their higher-performing classmates (Marsh et al., 2008). Thus, according to the BFLPE (Pekrun, Murayama, Marsh, Goetz, & Frenzel, 2019), adolescents receiving special education support in general classrooms might experience more unpleasant achievement emotions (i.e., less positive and more negative) than those receiving special education support in self-contained classrooms.

Researchers have also suggested that adolescents receiving no special education support might also suffer in more inclusive classrooms (Ruijs & Peetsma, 2009). However, previous studies indicated that the presence of students receiving special education support in general classrooms mostly has a positive effect on social relationships (e.g., understanding individual differences; Ruijs & Peetsma, 2009) and mixed effects on the academic performance of classmates receiving no special education support (Hienonen, Lintuvuori, Jahnukainen, Hotulainen, & Vainikainen, 2018; Szumski, Smogorzewska, &

Karwowski, 2017). Nevertheless, some studies indicated that this effect on academic performance is negative among adolescents (Dyson et al., 2004; Hienonen et al., 2018). Therefore, it is important to investigating whether adolescents receiving no special education support also experience some negative achievement emotions in more inclusive classrooms.

In the next few sections, are descriptions of the empirical background of the relationships between mathematics performance levels and EFs (Section 3.1); mathematics performance levels and achievement emotions (Section 3.2); gender and EFs and gender and achievement emotions (Section 3.3); and special education support and achievement emotions (Section 3.4).

3.1 Executive functions and mathematics performance levels

Figure 6 illustrates the empirical findings regarding behavioral and cognitive EF problems among students with different mathematics performance levels. Because empirical studies did not directly investigate the direction of relationships, the connections are described only by lines and not by arrows in Figure 6 (also in the following Figures 7 to 9). As this Figure 6 shows, previous studies have investigated only problems with attention behavior among students with mathematics difficulties (Martin et al., 2012; Raghubar et al., 2009; Wu et al., 2014), and few studies have focused on adolescents with mathematics difficulties (McGlaughlin, Knoop, & Holliday, 2005; Swanson, 2012).

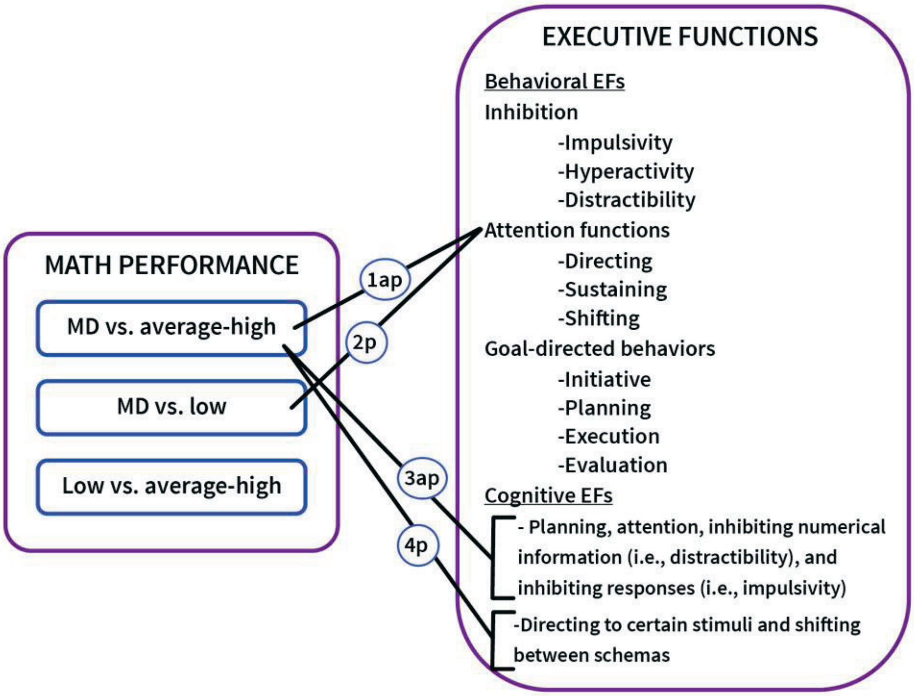

Figure 6. Empirical relationship between mathematics performance groups and executive functions. MD = mathematics difficulties; Low = low mathematics performance; average-high = average or higher mathematics scores; EFs = executive functions; p = found in primary school: ap = found among adolescents and in primary school.

3.1.1 Behavioral executive functions

Specifically, previous studies have found that high school adolescents and primary school children with mathematics difficulties have more parent-rated attention problems (i.e., parents rated students problems; Wu et al., 2014) and/or teacher-rated attention problems (Raghubar et al., 2009; Swanson, 2012) than those with average or higher mathematics scores (*Figure 6, link 1*). In addition, primary school children with mathematics difficulties have more teacher- or parent-rated attention problems than those with low mathematics performance (*Figure 6, link 2*: Raghubar et al., 2009; Wu et al., 2009). In turn, children with low mathematics performance did not differ in teacher-rated attention problems from those with average or higher mathematics scores (Wu et al., 2014). These studies suggest that primarily students with mathematics difficulties have problems with attention behaviors.

However, this is not necessarily clear among adolescents. McGlaughlin et al. (2005) found insignificant differences in self-reported attention problems between adolescents with mathematics difficulties and low mathematics performance in university. However, McGlaughlin et al. (2005) defined attention problems to include hyperactivity and impulsivity, which are not as critical as inattention in mathematics performance (Merrell & Tymms, 2001). Moreover, older adolescents and adults with mathematics difficulties have reported problems with planning and evaluation behaviors during interviews (Desoete, 2009). Hence, behavioral EF problems among adolescents with mathematics difficulties should be investigated comprehensively.

3.1.2 Cognitive executive functions

A few studies have also investigated cognitive EF problems among younger adolescents (11 to 13 years-old; Cai, Li, & Deng, 2013) and older adolescents (high school; Swanson, 2012) with mathematics difficulties. These studies have shown that adolescents with mathematics difficulties have more problems with cognitive tasks requiring planning, attention, inhibiting numerical information (i.e., distractibility; Cai et al., 2013), and inhibiting responses (i.e., impulsivity; Cai et al., 2013; Swanson, 2012) than those with average or higher scores (*Figure 6, link 3*).

Researchers have also found that primary school children with mathematics difficulties have similar cognitive EF problems (*link 3*; Kroesbergen, Van Luit, & Naglieri, 2003; Peng, Congying, Beilei, & Sha, 2012; Szücs, Devine, Soltesz, Nobes, & Gabriel, 2013). Primary school children with mathematics difficulties also have more problems with cognitive tasks requiring directing to certain stimuli (Reimann, Gut, Frischknecht, & Grob, 2013) and shifting between schemas (i.e., between letter and number; McLean & Hitch, 1999; van der Sluis, de Jong, & van der Leij, 2004) than those with average or higher mathematics scores (*link 4*). Nevertheless, the differences were not significant in less complex cognitive tasks requiring shifting between rules or responses (Toll, Van der Ven, Kroesbergen, & Van Luit, 2011; van der Sluis et al., 2004) or simple mathematical operations (Raghubar et al., 2009).

As students with mathematics difficulties tended to have several cognitive EF problems, it is also important to investigate whether they also have several behavioral EF problems in relation to their classroom contexts.

3.1.3 Correlation studies

Some investigations of relationships between EFs and mathematics performance also suggested that several EF problems should be investigated among students with different mathematics performance levels. Researchers have found that children's problems with attention (Fuchs et al., 2006; Martin et al., 2012; Raghubar et al., 2009), initiative (Dobbs, Doctoroff, Fisher, & Arnold, 2006; Finn, Pannozzo, & Voelkl, 1995), and planning behaviors (Clark et al., 2010) rated by teachers are related to their mathematics performance, at least in primary and preschool. Researchers have even found that teacher-rated attention predicted mathematics performance over and above working memory (Fuchs et al., 2006), suggesting that behavioral EFs play a significant role in students' mathematics performance.

However, not all behavioral EF problems are necessarily central to mathematics performance. Researchers have indicated that hyperactivity and/or impulsivity in primary school (Merrell & Tymms, 2001) and shifting attention problems in preschool (Clark et al., 2010) rated by teachers are not necessarily associated mathematics performance.

In summary, these studies together suggest that adolescents with mathematics difficulties might have several behavioral EF problems, although researchers have mainly focused on attention problems.

3.2 Achievement emotions and mathematics performance levels

Adolescents with mathematics difficulties and low mathematics performance might also experience unpleasant mathematics-related achievement emotions. As Figure 7 shows, the empirical findings of these relationships are limited to anxiety.

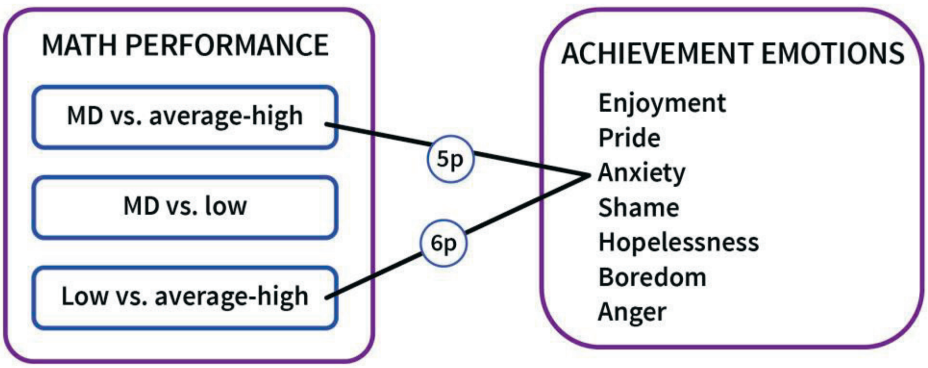

Figure 7. Empirical relationship between mathematics performance groups and achievement emotions. MD = mathematics difficulties; Low = low mathematics performance; average-high = average or higher mathematics scores; p = found in primary school.

More precisely, some studies have investigated anxiety among primary school students with different mathematics performance levels (Passolunghi, 2011; Wu et al., 2014). These studies found that primary school children with mathematics difficulties (*Figure 7, link 5*; Passolunghi, 2011; Wu et al., 2014) and with low mathematics performance (*link 6*; Wu et al., 2014) reported significantly more anxiety than children with average or higher mathematics scores. However, the differences between those with mathematics difficulties and those with low mathematics performance were not significant. Although these studies suggested that students with mathematics difficulties and low mathematics performance both experienced anxiety, this is not understood in relation to achievement emotions other than anxiety.

However, Stephanou (2011) found that adolescents (15–16 years old) perceiving their mathematics performance as unsuccessful reported fewer positive emotions such as pride, and more negative emotions such as anger, anxiety, and boredom, than those perceiving their performance as being successful. Nevertheless, students' mathematics performance was based on their experience instead of standardized mathematics test results (Stephanou, 2011). Hence, investigating whether adolescents with mathematics difficulties and low mathematics performance (based on an objective standardized test; Mazzocco, 2008) also experience specific unpleasant achievement emotions in mathematics is important.

In addition, researchers have found that mathematics-related enjoyment, pride, anger, anxiety, shame, boredom, and hopelessness are associated with mathematics performance among adolescents (Luo, Lee, Ng, & Ong, 2014; Pekrun et al., 2017). Together, these studies suggest that various mathematics-related achievement emotions should be investigated among adolescents with different mathematics performance levels.

3.3 Gender differences in executive functions and achievement emotions

Empirical findings suggest that it is important to consider gender when investigating EFs and mathematics-related emotions. Figure 8 illustrates the relationship between gender and EFs and gender and mathematics-related emotions. Next, these links are described systematically.

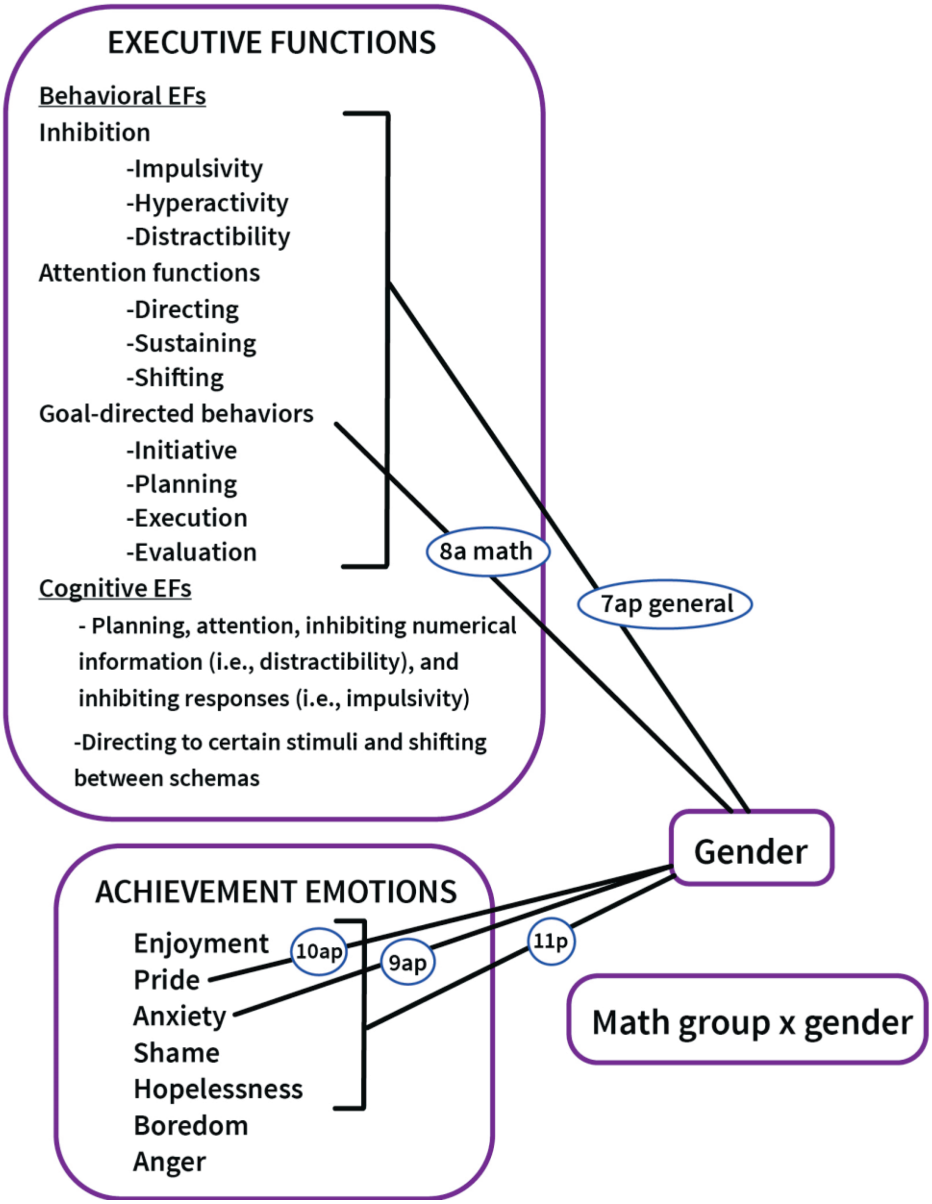

Figure 8. Empirical relationship between gender and EFs and between gender and achievement emotions. EFs = executive functions; math group x gender = interaction between mathematics performance groups and gender; a = found among adolescents; p = found in primary school; ap = found among adolescents and in primary school.

3.3.1 Executive functions and gender

Researchers have found that male children or adolescents had more problems than female children or adolescents with several teacher-rated behavioral EFs, including hyperactivity, impulsivity, distractibility, attention functions, initiative, planning, execution, and evaluation (*Figure 8, link 7*; Dobbs et al., 2006;

Huizinga & Smidts, 2011; Klenberg et al., 2010; Merrell & Tymms, 2001). Researchers have also found that in mathematics, male adolescents self-reported more goal-directed problems than female adolescents (*link 8*; Cleary & Chen, 2009; Kenney-Benson, Pomerantz, Ryan, & Patrick, 2006).

Notably, gender differences were less clear in cognitive EFs. Some studies have found insignificant gender differences in cognitive tasks requiring planning, attention, and inhibiting responses and irrelevant stimulus among adolescents (Cai et al., 2013). In turn, other studies have shown that male children or adolescents perform less well than females on cognitive tasks requiring planning, attention (Naglieri & Rojahn, 2001), and sustaining attention (Sussman & Tasso, 2013).

Additionally, Wu et al. (2014) revealed that primary school females struggling with mathematics might also have problems with parent-rated attention. Hence, to support females and males with mathematics difficulties it is important to explore the interaction between gender and mathematics performance groups. This interaction effect indicated whether there are gender variations in EF problems across mathematics performance groups (difficulties, low, and average or higher).

3.3.2 Emotions and gender

Although males seem to have more behavioral EF problems than females, the gender differences in mathematics-related achievement emotions are opposite. Several studies have found that female children or adolescents reported more mathematics-related anxiety than males (Figure 8, *link 9*; e.g., Devine, Fawcett, Denes, & Dowker, 2012; Else-Quest, Hyde, & Linn, 2010; Miller & Bichsel, 2004; Organisation for Economic Co-operation and Development [OECD], 2004).

The gender differences in other mathematics-related achievement emotions is less clear among adolescents. However, Stipek and Gralinski (1991) found that females in junior high school (13 and 14 years old) and in primary school reported less pride after mathematics success than males (*link 10*), but not more shame after a mathematics failure. Moreover, Frenzel et al. (2007a) found that that females in primary school reported less enjoyment and pride and more anxiety, hopelessness, and shame in mathematics than males (*link 11*).

To support the mathematics learning of females and males struggling with mathematics, it is important to investigate whether mathematics-related achievement emotions vary across females and males with different mathematics performance levels. However, Wu et al. (2014) found no significant interaction effect between gender and mathematics performance groups on anxiety, indicating that that there are no gender variations in anxiety across mathematics performance groups. As Wu et al. (2014) focused only on primary school children's anxiety, more research is needed to understand whether this interaction exists among other mathematics-related achievement emotions among adolescents.

3.4 Special education support and achievement emotions

Students struggling with mathematics might get special education support. Some empirical evidence indicates that there is a relationship between special education support and some achievement emotions. Figure 9 illustrates these relationships.

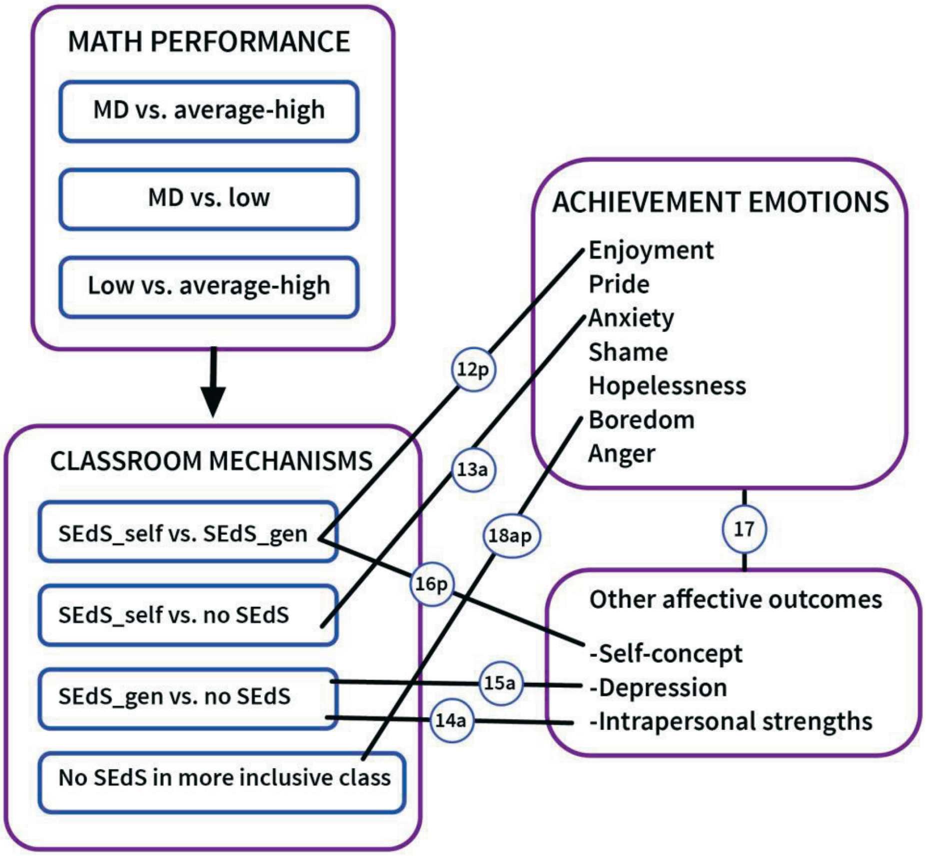

Figure 9. Empirical relationship between special education support and achievement emotions. MD = mathematics difficulties; Low = low mathematics performance; average-high = average or higher mathematics scores; SEdS_self = receiving special education support (SEdS) in self-contained classrooms; SEdS_gen = receiving SEdS in general classrooms; a = found among adolescents; p = found in primary school; ap = found among adolescents and in primary school.

3.4.1 Adolescents receiving special education support

Specifically, empirical evidence indicated that primary school students receiving special education support in self-contained classrooms in special schools reported more enjoyment than those receiving special education support in general classrooms (*Figure 9, link 12*; Kocaj et al., 2018). In addition, the evidence indicated that adolescents receiving special education support in self-contained classrooms reported less anxiety than those receiving no special education support (*link 13*; Wiest, Wong, Cervantes, Craik, & Kreil, 2001). These studies suggested that several achievement emotions should be also investigated among adolescents receiving special education support in these two classroom settings.

Empirical evidence also revealed that there are relationships between special education support and other affective outcomes—intrapersonal strength (e.g., enthusiasm for life), depression (e.g., everything went wrong), and self-concept. According to this evidence, adolescents receiving special education support in general classrooms reported less intrapersonal strength (*link 14*; Lappalainen, Savolainen, Kuorelahti, & Epstein, 2009) and more depression (*link 15*; Valås, 2001) than adolescents receiving no special education support. In turn, primary school students receiving special education support in self-contained classrooms reported higher mathematics-related self-concept than those receiving special education support in general classrooms (*link 16*; Kocaj et al., 2018). As affective outcomes such as self-concept might relate to achievement emotions according to the control-value theory (*link 17*; Pekrun, 2006), there might be differences in several mathematics-related achievement emotions between adolescents receiving special education support in self-contained and general classrooms.

3.4.2 Adolescents receiving no special education support

Additionally, those receiving no special education support might experience negative emotions in inclusive classrooms. A few studies have found that primary school children and adolescents receiving no special education support reported in the interview to experience boredom in the inclusive classrooms, as they are taught too slowly and learned less (*link 18*; Litvack, Ritchie, & Shore, 2011; Vaughn, Schumm, Klingner, & Saumell, 1995). These studies suggested that adolescents receiving no special education support might report boredom if the proportion of students receiving special education support is higher in general classrooms.

Support mechanisms might also suggest that adolescents receiving no special education support report other negative achievement emotions in inclusive classrooms, although there is no empirical evidence of this issue. Specifically, teachers might focus on students receiving special education support in inclusive classrooms, forcing students receiving no special education support to study alone (Dyson et al., 2004; Ruijs et al., 2010). Studying without teacher support may reduce adolescents' enjoyment and increase their anxiety and hopelessness (Ahmed et al., 2010; Sakiz et al., 2012). In addition, students receiving no special education support might receive less peer support when the proportion of lower-performing students receiving special education support is higher in classrooms; thus, they may experience less enjoyment (Ahmed et al., 2010; Kocaj et al., 2018). These studies suggested that achievement emotions of those receiving no special education support should also be investigated in more inclusive classrooms.

4 Research tasks and hypothesis

The overall aim in the present study was to investigate behavioral EF problems and mathematics-related achievement emotions among adolescents with different mathematics performance level, and whether special education support is associated with such emotions. Figure 10 summarizes empirical evidence behind this study. This evidence is described in more detailed in Section 3. Research questions and hypotheses are based on this empirical framework.

As Figure 10 shows, empirical studies often have investigated attention behaviors (*links 1* and *2*), cognitive EFs (*links 3* and *4*), and anxiety (*links 5* and *6*) among students with mathematics difficulties and low mathematics performance. Hence, several behavioral EFs and mathematics-related achievement emotions among those students have not yet been investigated.

In addition, empirical studies have explored gender differences in several behavioral EFs (*link 7* and *link 8*) and mathematics-related achievement emotions (*link 9* to *11*). Although these studies suggested that behavioral EF problems are more characteristic among males and negative mathematics-related achievement emotions more so among females, it is unclear whether these issues are similar among females and males with different mathematics performance levels.

Some empirical studies have also investigated affective outcomes among students receiving special education support in general education and self-contained classrooms (*link 12* to *16*), and some interview studies investigated boredom among adolescents receiving no special education support in inclusive classrooms (link 18). To extend this limited empirical background, it is important to investigate whether these links exists in several mathematics-related achievement emotions.

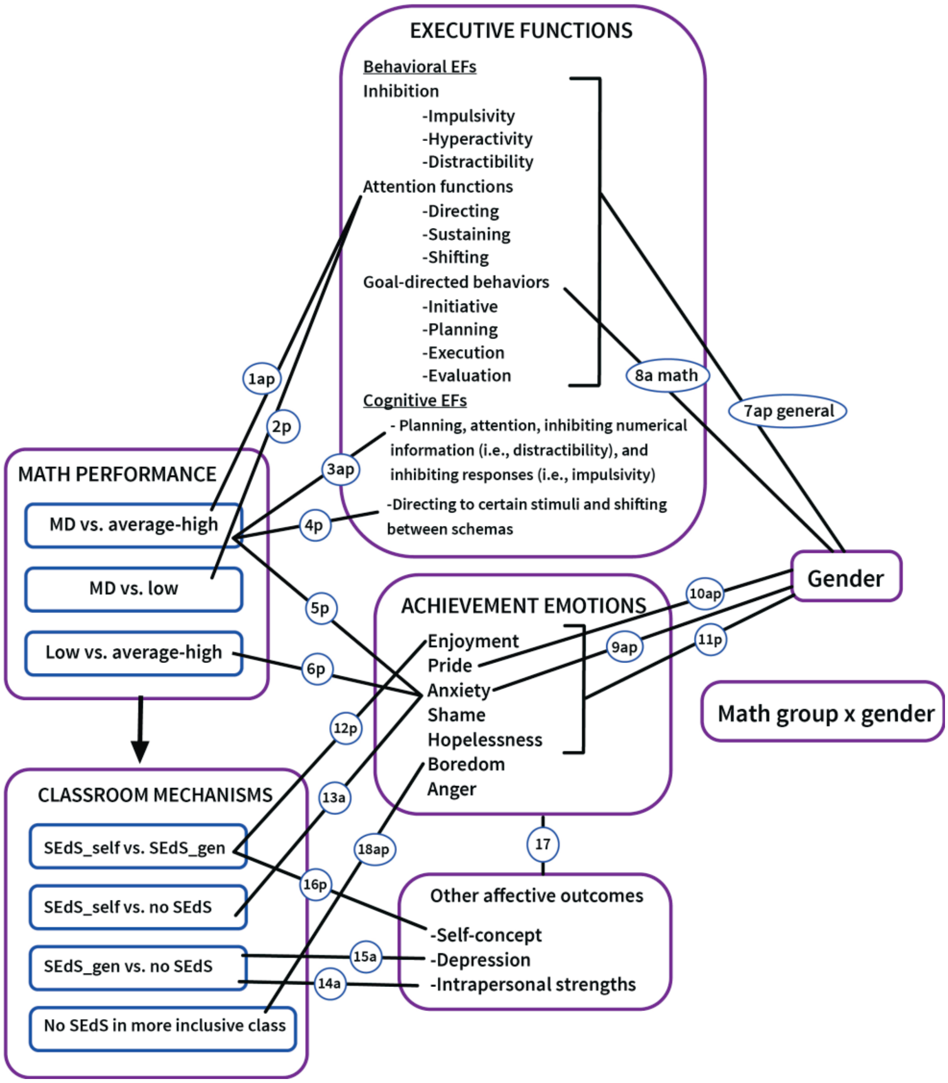

Figure 10. Summarized empirical framework. MD = mathematics difficulties; Low = low mathematics performance; average-high = average or higher mathematics scores; EFs = executive functions; SEdS_self = receiving special education support (SEdS) in self-contained classrooms; SEdS_gen = receiving SEdS in general classrooms; math group x gender = interaction between mathematics performance groups and gender; a = found among adolescents; p = found in primary school; ap = found among adolescents and in primary school.

Considering the above, an aim of the present study was to investigate behavioral EF problems and mathematics-related achievement emotions among adolescents with mathematics difficulties and low mathematics performance, as well as whether these relationships vary between the genders. Furthermore, mathematics-related achievement emotions among adolescents receiving special education support in general and self-contained classrooms were investigated.

Finally, the emotions among adolescents receiving no special education support in more inclusive mathematics classrooms were investigated. The present dissertation study is based on three original publications, which are referred to in the text by Roman numerals (studies I – III).

First, study I investigated teacher-rated behavioral EF problems—distractibility, impulsivity, hyperactivity, directing, sustaining, shifting, initiative, planning, execution, and evaluation—among adolescents with different mathematics performance levels. Table 7 presents a summary of the research questions and hypotheses of this study.

Table 7. The research questions and hypotheses of the study I.

Questions (Q)	**Hypotheses (H)**
Q1. Are there differences in behavioral EF problems among groups with math difficulties, low math performance, and average or higher math scores?	H1. Based on previous studies (Martin et al., 2012; Raghubar et al., 2009; Swanson, 2012; Wu et al., 2014), this study hypothesized that group with math difficulties had more attention problems than group with average or higher math scores.
Q2. Are there gender differences in the behavioral EF problems in mathematics?	H2. Based on previous studies (Cleary & Chen, 2009; Dobbs et al., 2006; Huizinga & Smidts, 2011; Kenney-Benson et al., 2006; Klenberg et al., 2010; Merrell & Tymms, 2001), this study proposed that males have more behavioral EF problems in mathematics than females.
Q3. As a normative study found significant gender differences in all EFs explored in this study and suggested that these EFs should be considered separately by gender (Klenberg et al., 2010), this study also investigate the interaction between gender and the three math performance groups in behavioral EFs.	

Secondly, study II expands this research on mathematics-related achievement—enjoyment, pride, anger, anxiety, shame, hopelessness, and boredom—among adolescents with different mathematics performance levels. Table 8 summarizes the research questions and hypotheses of this study.

Table 8. The research questions and hypotheses of the study II.

Questions (Q)	**Hypotheses (H)**
Q4. Are there differences in mathematics-related achievement emotions among groups with mathematics difficulties, low mathematics performance, and average or higher mathematics scores?	H4. Based on previous studies (Passolunghi, 2011; Wu et al., 2014), this study assumed that groups with mathematics difficulties and low mathematics performance reported more anxiety than group with average or higher mathematics scores.
Q5. Are there gender differences in mathematics-related achievement emotions?	H5. Based on the previous literature, this study proposed that females reported more unpleasant mathematics-related achievement emotions than males (Frenzel et al., 2007a; Stipek & Gralinski, 1991), and this gender difference is most evident in anxiety (Else-Quest et al., 2010; Miller & Bichsel, 2004; OECD, 2004).
Q6. Is there interaction between math performance groups and gender in mathematics-related achievement emotions?	H6. Based on Wu el al.'s (2014) finding, this study hypothesized that there are no gender variations in the relation between math performance groups and anxiety.

Because these adolescents can also get special education support in their mathematics learning and this support might be related to their affective outcomes, study III broadened this research by studying the relationships between special education support and mathematics-related achievement. Notably, mathematics performance and gender at the individual and classroom levels and class size at the classroom level were controlled for. This controlling was done because previous studies have shown that these variables are associated with mathematics-related achievement emotions at the individual and/or the classroom levels (Frenzel et a., 2007b; Khajavy, MacIntyre, & Barabadi, 2018; Pekrun et al., 2017; Pekrun et al., 2019). Table 9 summarizes the research questions and hypotheses of this study.

Table 9. The research questions and hypotheses of the study **III**.

Questions (Q)	**Hypotheses (H)**
Q7. Do adolescents receiving special education support in self-contained mathematics classrooms differ in mathematics-related achievement emotions from those receiving special education support in general mathematics classrooms?	H7. Based on the literature (Kocaj et al., 2018; Szumski & Karwowski, 2015), this study hypothesized that adolescents receiving special education support in self-contained classrooms report more pleasant mathematics-related emotions—enjoyment—than adolescents receiving special education support in general classrooms.
Q8. Do adolescents receiving special education support in self-contained mathematics classrooms differ in mathematics-related achievement emotions from those receiving no special education support? Those receiving no special education support were in general classrooms with and without adolescents receiving special education support.	H8. Based on Wiest et al.'s (2001) study, this study proposed that adolescents receiving special education support in self-contained classrooms report less mathematics-related anxiety than those receiving no special education support.
Q9. Do adolescents receiving special education support in general mathematics classrooms differ in mathematics-related achievement emotions from those receiving no special education support?	H9. Based on the literature (Lappalainen et al., 2009; Valås, 2001), this study assumed that adolescents receiving special education support in general classrooms report more some unpleasant mathematics-related achievement emotions than those receiving no special education support.
Q10. Is the proportion of adolescents receiving special education support in general mathematics classrooms associated with the mathematics-related achievement emotions of adolescents receiving no special education support?	H10. Based on previous findings (Litvack et al., 2011; Pekrun, 2006; Vaughn et al., 1995), this study hypothesized that a higher proportion of adolescents receiving special education support in general classrooms has an effect on the boredom of adolescents receiving no special education support.

5 Method

As an introduction it is worth mentioning that the all three original studies were drawn from the same large survey implemented in spring 2010. The survey was funded by a three-year grant from the Finnish Cultural Foundation in Finland. In undertaking the project, the Finnish code of ethical principles of research in the humanities and social and behavioral sciences was followed (National Advisory Board on Research Ethics, 2009). According to these principles, this study did not involve any of the circumstances that would require an ethics review. The permission for the survey was obtained from the municipal education departments and the head teachers, and informed consent was obtained from the participants' parents. Next, there is a description of the participants (Section 5.1), measures (Section 5.2), and data-analysis (Section 5.3) used in these studies. More research-specific descriptions can be found in the actual articles.

5.1 Participants

In all three original studies used in this dissertation the participants were from the sample of eighth-grade students (14 to 15-years-old) from 27 Finnish compulsory schools in five provinces in Finland. The Finnish educational system consists of nine years of compulsory schooling (six years of primary school and three years of lower secondary school), and in Finland, most children begin school during the year they turn seven.

In these studies, clustering, stratified, and systematic sampling methods were used (Lehtonen & Pahkinen, 2004). The school sample was drawn from the statistical list of Finnish compulsory schools (i.e., clustering sampling). Before drawing the sample, the schools were sorted by province and by municipality or city in each province (i.e., implicitly stratified sampling). Hence, the sample was selected according to the ratio of schools in each province. Systematic sampling was used to select schools at regular intervals from the stratified list.

These three sampling methods were used because it allowed a geographically representative sample of the Finnish schools to be achieved. Indeed, there were more schools from the large provinces than from the small ones. The study sample included municipalities and cities of a range of sizes, and the school sizes varied representatively from small (n = 65) to large (n = 658). The demographic data of the participants in the three original studies are summarized in Table 10.

Table 10. Participants in the three studies.

Variables across studies	Total *n*	F *n*	M *n*	Math *M(SD)*	Class size *M(SD)*
Study I					
Schools	27				
Students	619				
Mathematics difficulties	124	67	57	9.45(2.57)	
Low mathematics performance	140	73	67	14.74(1.10)	
Average or higher mathematics scores	355	141	214	22.06(3.80)	
Study II					
Schools	27				
Students	1,358				
Mathematics difficulties	136	76	60	9.43(2.59)	
Low mathematics performance	166	97	69	14.75(1.11)	
Average or higher mathematics scores	1,056	532	524	25.54(5.40)	
Study III					
Schools	27				
Student level					
Students	1,379				
Receiving SEdS in self-contained math classes	73	35		12.81(6.25)	
Receiving SEdS in general math classes	127	60		15.99(5.79)	
Receiving no SEdS in math[a]	1,179	629		24.00(6.75)	
Classroom level					
All classes	88				15.67(5.25)
Self-contained classes	11			12.57(3.59)	6.64(2.38)
General classes	77				
General classes with SEdS students	44			22.49(2.98)	17.39(4.53)
General classes without SEdS students	33			23.9(3.27)	16.39(3.77)

Note. F = females; M = males; SEdS = special education support. [a]Of those receiving no SEdS, 638 were in classes with students receiving SEdS and 541 were in classes with no students receiving SEdS.

For the purpose of the studies I and II, adolescents were divided into the groups with mathematics difficulties, low mathematics performance, and average or higher mathematics scores[1]. The cutoff percentiles of the adolescents identified as having mathematics difficulties and low mathematics performance were based on the theory previously presented (see Section 2.1). The mathematics scores that matched the cutoff percentiles were determined based on the whole sample. The cutoff score was 12 or below (below the 11th percentile) for mathematics difficulties, between 13 and 16 (between the 11th and 25th percentiles) for low mathematics performance, and above 17 (above the 25th; maximum 40) for average or higher mathematics scores on a standardized mathematics assessment (Räsänen & Leino, 2005). The number of the participants in these mathematics performance groups are summarized in Table 10.

Study III focused on emotions among adolescents receiving special education support (SEdS) in different classroom settings. Hence, the eight-grade participants were divided into a group receiving SEdS in self-contained mathematics classrooms, a group receiving SEdS in general mathematics classrooms, and a group receiving no SEdS. Because this study also investigated whether the proportion of students receiving SEdS in general classrooms is related to students' emotions, the classrooms (*n* = 88) were divided into general and self-contained mathematics classrooms. The number of participants in these SEdS groups and the number of classrooms are also summarized in Table 10.

5.2 Measures and procedures

The survey materials were sent to the participant schools by regular mail. General survey instructions for teachers were provided in the test material. In the feedback, the teachers reported that the implementation of the survey was clear. After completion of the study, the teachers collected all the materials and returned them to the researchers by regular mail.

In this survey, data were collected with three assessments that measure students' mathematics performance, EF problems and mathematics-related achievement emotions. As shown in Table 11, mathematics performance was measured in all three studies, EF problems in study I, and mathematics-related achievement emotions in study II and III. These three measures are described in more detail below.

[1]To harmonize terminology between the three studies, the term typical mathematics performance (Study II) was replaced by average or higher mathematics scores in this thesis.

Table 11. Measures of the three studies.

	Mathematics performance	EF problem	Mathematics-related emotions
Studies	I, II, III	I	II, III
Name	KTLT	ATTEX	AEQ-M
Respondents	Students	Teachers	Students
Context	Algebra, arithmetic, word problems, algebra, geometry, unit conversion	in relation to math classroom	in relation to math classroom, learning, and testing
Example	Equation solving	Problems focusing on instructions	Pride after the successful math exam

Note. KTLT = Koulutuksen tutkimuslaitoksen testi; ATTEX = Attention and Executive Functions Rating Inventory; AEQ-M = Achievement Emotions Questionnaire–Mathematics.

5.2.1 Mathematics performance

Mathematics performance was assessed using the standardized assessment normed for the Finnish population (KTLT; Räsänen & Leino, 2005). This test was used as it was designed to define adolescents' mathematics difficulties, it has shown good internal reliability in several other studies (e.g., Korhonen, Linnanmäki, & Aunio, 2014), and it has good criterion validity with other measures of mathematics performance (Räsänen & Leino, 2005).

The focus of the KTLT test is core mathematics skills in grades 7–9. The KTLT assesses students' performance in arithmetic, word problems, algebra, geometry, and unit conversion. The KTLT test is a paper-and-pencil test consisting of 40 items, with one point for a correct answer and zero for an incorrect answer. Test scores range from 0 to 40. Of the four versions of the KTLT test (A, B, C, and D), version B was chosen for this study as it showed the highest internal reliability ($\alpha = .90$; Räsänen & Leino, 2005). The teachers read the KTLT instructions to students before its implementation. Students had 40 minutes to complete the test.

5.2.2 Executive functions in mathematics classrooms

EF problems were examined using the Attention and Executive Functions Rating Inventory (ATTEX; Klenberg et al., 2010). This inventory was used as it measures various EFs in relation to students' classroom context. It has shown good internal reliability for each scale and good criterion validity with another behavioral rating scale (DuPaul, Power, Anastopoulos, & Reid, 1998) for a normative Finnish sample (7 to 15-year-old).

Teachers rated students' behavior on a 3-point scale (not, sometimes, and often a problem). The ATTEX consists of 55 items grouped into 10 scales:

distractibility (four items; e.g., activities are interrupted by external stimuli), impulsivity (nine items; e.g., waiting for a turn), hyperactivity (seven items; e.g., staying in one's seat), directing attention (five items; e.g., focusing on instructions), sustaining attention (six items; e.g., working a long time), shifting attention (four items; e.g., changing from one activity to another), initiative (five items; e.g., starting tasks without help), planning (four items; e.g., planning tasks before starting), execution of action (eight items; e.g., completing tasks), and evaluation (three items; e.g., evaluating own performance).

Teachers were instructed to evaluate students' EF problems by choosing the alternative of the ATTEX that best corresponded to the student's typical behavior in the mathematics classroom context.

5.2.3 Mathematics-related achievement emotions

Mathematics-related achievement emotions were assessed using the Achievement Emotions Questionnaire–Mathematics (AEQ-M; Pekrun et al., 2005). The AEQ-M was used because it measures diverse emotions in mathematics, is based on a broad theory of emotions, and has shown good internal reliability in several studies (e.g., Pekrun et al., 2017; Sakiz et al., 2012).

The AEQ-M is a student-reported measure that assesses typical achievement emotions (trait-like) in relation to three mathematics situations, including classroom, learning, and testing. The assessment contains 60 items measuring enjoyment (10 items, e.g., enjoyment in class), pride (6 items, e.g., pride after a test), anger (9 items, e.g., anger because of homework), anxiety (15 items, e.g., too anxious to take a test), shame (8 items, e.g., shame after a test), hopelessness (6 items, e.g., hopelessness during a test), and boredom (6 items, e.g., boredom during homework). Respondents were asked to express their emotions on a five-point Likert scale.

The original English AEQ-M (Pekrun et al., 2005) was translated into Finnish by a bilingual expert and was then pilot tested in a Finnish school. Thirty students from two classes and ten students receiving special education completed the pilot questionnaire and offered feedback to their teachers and the researcher. No negative feedback regarding the language and the fulfillment of the AEQ-M was reported, and the students reported that they understand the questionnaire.

In this survey study, students completed the AEQ-M in about 30 minutes at the end of the other mathematics lesson. The teachers read the instructions relating to the AEQ-M aloud to the students. Before the AEQ-M was administered, students were assured of the confidentiality of their responses, asked to express their opinion, and told that there were no right or wrong answers.

5.3 Data analysis

Table 12 summarizes the preliminary and data analyses in the three original studies. Study I was an investigation of students' EF problems and study II was an investigation of emotions among three mathematics performance groups and whether these relationships vary between the genders. These studies focused on observed manifest variables, including gender, ATTEX scales (EF problems), and AEQ-M scales (emotions). Hence, analyses that were designed for manifest variables were used, including analysis of variance (ANOVA).

On the other hand, study III was an investigation of the relationships between special education support and emotions at the individual and classroom levels. Mathematics performance and gender were also controlled for at the individual and classroom levels, and class size at the classroom level. Hence, more complex analysis methods were used in this study, including confirmatory factor analysis (CFA) and multilevel modeling (MLM). These methods were designed for latent variables or/and they allowed for classroom-level analyses. Specifically, the focus of study III was on both latent variables (emotions and mathematics performance) and manifest variables (gender and special education groups). The sections that follow discuss the preliminary and main analyses used in the three original studies.

Table 12. Analyses of the three studies.

Studies	Variables	Preliminary analyses	Main analyses
I	- Manifest: ATTEX scales, math performance groups, and gender	- No imputation - Scale statistics	- MANOVA and ANOVA
II	- Manifest: AEQ-M scales, math performance groups, and gender	- No imputation - Scale statistics	- MANOVA and ANOVA
III	- Latent: Emotions and mathematics performance - Manifest: Special education groups and gender	- Imputation - CFA - Measurement invariance	- SEM - MLM

Note. ATTEX = Attention and Executive Functions Rating Inventory; AEQ-M = Achievement Emotions Questionnaire–Mathematics; CFA = confirmatory factor analysis; MANOVA = multivariate analysis of variance; ANOVA = analysis of variance; SEM = structural equation modeling; MLM = multilevel modeling.

5.3.1 Preliminary analyses

In this section, the preliminary analyses used for the three original studies are described. These include imputations, scale statistics, confirmatory factor analysis, model fit indices, and measurement invariance testing.

5.3.1.1 Imputation

In studies I and II, missing data for the ATTEX (0.08%) and AEQ-M items (0.5%) were not imputed. The missing data in single ATTEX items (less than 1.2%) and AEQ-M items (less than 1.1%) were also minimal. In these two studies, imputation was not used because the amount of missing data was small, and the results did not change if analysis in these studies was run with non-imputed or imputed data.

In study III, the missing data from the AEQ-M items (0.5%) were imputed in SPSS (version 25) using the expectation-maximization algorithm (EM; Dempster, Laird, & Rubin, 1977). Other AEQ-M items served as auxiliary variables to impute the missing item values. Imputation was used because listwise deletion reduces the analytic sample size, and it is advisable to have a larger sample to implement more complex models (Hoyle & Gottfredson, 2014). Furthermore, the EM algorithm was used because researchers have shown that this algorithm produced estimates close to those of the original values (Musil, Warner, Yobas, & Jones, 2002; Rubin, Witkiewitz, St. Andre, & Reilly, 2007).

The EM algorithm is a general algorithm for maximum-likelihood estimation where the data are "incomplete"—including missing data (Dempster et al., 1977). Generally speaking, the EM algorithm alternates between two steps, called the expectation step (i.e., the E-step) and the maximization step (i.e., the M-step), respectively. In the E-step, the missing values are estimated by calculating expected likelihood values using known values. In the M-step, the parameters are re-estimated by maximizing the values found in the E-step. Once new parameter values were generated, E-step and another M-step can be repeated. This process continues until the estimates reach the local maximum, the optimum value.

5.3.1.2 Scale statistics

This section presents statistics for ATTEX scales (EF problems) and AEQ-M scales (emotions). Only a portion of this information could be found in the original articles, so the results are presented in this section instead of section 6, which provides an overview of the original studies.

The reliabilities of the ATTEX and AEQ-M scales were estimated using Cronbach's alpha (α) coefficients. The reliabilities of the ATTEX scales ranged from good ($0.8 \leq \alpha < 0.9$) to excellent ($\alpha \geq 0.9$). Similarly, the reliabilities of the AEQ-M scales ranged from good ($0.8 \leq \alpha < 0.9$) to excellent ($\alpha \geq 0.9$).

In order to understand the symmetry of the ATTEX and AEQ-M scales, the skewness of these variables was also considered. The skewness varied from −0.03 to 1.5 for ATTEX scales and was within the criterion parameters for univariate normality (skewness < |2|; George & Mallery, 2010). The highest skewness was for hyperactivity, for which the skewness only exceeded |1|. This was understandable because hyperactivity is a strong executive function (Klenberg et al., 2010) and occurrences of hyperactivity were relatively small (See Table 2 in original article I [study I]). Similarly, the skewness varied from −0.03 to 1.3 for all AEQ-M scales, which were within the criterion parameters for univariate normality (skewness < |2|; George & Mallery, 2010). The highest skewness occurred for shame, for which the skewness only exceeded |1|. This was understandable because shame was a strong achievement emotion (Pekrun, 2006) and occurrences of shame were relatively minimal (See Table 3 in original article II [study II]).

Subsequently, the discriminant validities of the ATTEX and AEQ-M scales were analyzed. Pearson product-moment correlations between the ATTEX scales ranged from medium to high (from 0.41 to 0.79). However, the correlations were always lower than the validity coefficient's magnitude ($r_{ab} < \sqrt{\alpha_a \cdot \alpha_b}$, where r_{ab} was a correlation between two scales [a and b] and α was the reliability of these scales). This indicated discriminant validity of the ATTEX scales (McCoach, Gable, & Madura, 2013). Similarly, Pearson product-moment correlations between the AEQ-M scales ranged from medium to high (from −.18 to .87). However, the criterion for discriminant validity was also met for the AEQ-M scales (McCoach et al., 2013).

Overall, these findings showed that the EFs and the emotion scales were separable, had sufficient symmetry, and had reliabilities that ranged from good to excellent.

5.3.1.2 Confirmatory factor analysis

In study III, the model fits of the latent achievement emotion and the latent mathematics performance constructs were tested using CFA. This method was used as it is a frequently used tool in the development and analysis of measurements and it controlled for measurement errors—that, is the amount of variance in the items that is not explained by the factor (Brown, 2006; Rencher & Christensen, 2012; Vehkalahti & Everitt, 2019). Specifically, this allows the researcher to test if the factor structure that is based on theoretical knowledge fits the data. All CFA models were estimated with the robust maximum likelihood estimator (MLR), as it is robust to nonnormality of the observed variables using the Mplus statistical package (version 7; Muthen & Muthen, 1998–2013).

The CFA model consists of latent variables—factors. Latent variables cannot be measured directly but can be assumed to relate to measurable manifest variables that serve as factor indicators (Brown, 2006; Rencher & Christensen, 2012). The CFA will follow the usual statistical paradigm, including hypothesizing an identifiable model, fitting model parameters, and assessing the goodness of model fit (Rencher & Christensen, 2012).

5.3.1.3 Model fit indices

In study III, goodness of fit of the latent emotion constructs and mathematics performance were evaluated using fit indices. Model fit indices indicate how well the model fits the sample data and which proposed model has the most superior fit (Hooper, Coughlan, & Mullen, 2008).

A combination of fit indices was used, including the comparative fit index (CFI), Tucker–Lewis index (TLI), and root mean square error of approximation (RMSEA). CFI and TLI values greater than 0.90 and 0.95 reflect acceptable and excellent model fits. RMSEA values less than 0.05 and 0.08 reflect close and reasonable model fits, respectively (Marsh, Hau, & Wen, 2004). This study did not use the chi-square significance test because the chi-square statistic is sensitive to sample size and often rejects the model when large samples are used (Hooper et al., 2008).

Additionally, study III used composite reliability (CR; Geldhof, Preacher, & Zyphur, 2014) to measure the internal consistency reliability of the emotion factors. The composite reliability was used because it is calculated using factor loadings; and thus, giving precise estimates for latent construct (Geldhof et al., 2014).

5.3.1.4 Measurement invariance

In study III, measurement invariance procedures were used to test whether the latent emotion constructs were invariant across the three SEdS groups: receiving no SEdS (1), receiving SEdS in general classrooms (2), and receiving SEdS in self-contained classrooms (3). This procedure allows researchers to examine whether participants from different groups interpret the same measure in a similar way (van de Schoot, Lugtig, & Hox, 2012). All models were estimated with the MLR (robust to nonnormality) in Mplus.

Multiple-group CFA was used to test the measurement invariance by specifying a series of nested models for each achievement emotion. Specifically, establishing measurement invariance involves running a set of increasingly constrained models, and testing whether differences between these models are significant (Kline, 2011; Putnick & Bornstein, 2016; van de Schoot et al., 2012).

According to Chen (2007), support for the more restrictive model requires a change in the CFI (ΔCFI) value of < 0.01 or a change in the RMSEA (ΔRMSEA) value of < 0.015 (see section 5.3.1.3). The Bayesian information criterion (BIC) was also used to compare models. The BIC value should be lower in a more restrictive model than a less restrictive model (van de Schoot et al., 2012). Notably, in this study the chi-square difference test was not used because this test of measurement invariance is over-sensitive to the sample size if compared with ΔCFI and ΔRMSEA (Chen, 2007; Meade, Johnson, & Braddy, 2008).

Next, invariance testing is described step by step based on the literature (Kline, 2011; Putnick & Bornstein, 2016). Specifically, first the configural invariance were tested. In this step, the configural model was specified, imposing no invariance constraints on the factor loadings and indicator intercepts (may differ across groups) but the same item had to be associated with the same factor in each group. A good model fit suggests that the overall factor structure holds similarly for all groups.

If configural invariance was supported, the metric invariance was tested next. In this step, the configural model was compared to the metric invariance model where the factor loadings were constrained to equality across the groups. If the model fit was not significantly worse in the (more restrictive) metric invariance model compared to the configural invariance model (ΔCFI < 0.01, ΔRMSEA < 0.01, and the BIC value did not increase), metric invariance was supported. This indicated that the factor loadings were equivalent across the groups.

If metric invariance was supported, the scalar invariance was tested next. In this step, the metric invariance models were compared to the scalar invariance models, in which the indicator intercepts were also constrained to equality across the groups. If the model fit was not significantly worse in the (more restrictive) scalar invariance model compared to the metric invariance model, it indicated that the item intercepts are also equivalent across groups. These three levels of invariances were required for comparing latent mean differences across groups.

5.3.2 Main analysis

The three main analysis methods are described in this section. Notably, multivariate analysis of variance (MANOVA) and ANOVA were used in studies I and II. These analyses were chosen as they have often been preferred when differences between groups in manifest variables were examined (Warne, 2014). However, with study III, the aim was to investigate relationships between special education support and latent emotions at the individual and classroom levels. Hence, more complex analysis methods were used, including structural equation modeling (SEM) and MLM.

5.3.2.1 Analysis of variance

MANOVA and ANOVA were used to investigate differences between mathematics performance groups in behavioral EFs in study I and in mathematics-related achievement emotions in study II. These analyses are described on a study-by-study basis in Section 6.1 and 6.2.

In the analysis of variance, the independent variable is a nominal variable that has two or more values (Warne, 2014), such as three mathematics performance groups and gender. The independent variable is interval or ratio scaled, such as means of EF or achievement emotion scales (Warne, 2014). The

ANOVA is used to test if the differences between the group means differ significantly. The MANOVA is merely the ANOVA that has been mathematically extended to apply to situations with two or more dependent variables.

Usually, MANOVA should be used first as it determines whether independent variables(s) have main effects on the multiple dependent variables at the same time and reduces the likelihood of Type 1 error (false significant finding; Warne, 2014). Afterwards, if MANOVA is significant, separate ANOVAs are often used to test the effect of the independent variables on each dependent variable at a time. When the differences in ANOVAs are significant and there are three or more groups, post hoc tests are necessary to provide information about the specific group differences.

The effect size quantifies the relationships between the independent and dependent variables. Effect sizes are as partial eta squared (η_p^2: small ≥ 0.01, medium ≥ 0.06, large ≥ 0.14) for the MANOVA and ANOVA analyses, and in terms of Cohen's *d* (*d*: small ≥ 0.2, medium ≥ 0.5 and large ≥ 0.8) for the post hoc tests.

5.3.2.2 Structural equation modeling

In study III, SEM was used to investigate whether students receiving SEdS in self-contained classrooms differ in emotions from students receiving and not receiving SEdS in general classrooms. SEM was used as emotions were obtained as latent constructs and SEM accounted for measurement errors (Raykov & Marcoulides, 2000). However, it should be noted that the results were similar if MANOVA and ANOVA were used. All SEM models were estimated with the MLR in Mplus.

Specifically, SEM extends the CFA by allowing for both dependent and independent latent variables and paths between them (Vehkalahti & Everitt, 2019). SEM typically refers to modeling where path relationships are investigated between latent and manifest variables in single level analysis. For example, whether a manifest (i.e., SEdS group) and a latent construct (i.e., math performance) predict a latent outcome variable (i.e., achievement emotion) could be investigated.

5.3.2.3 Multilevel modeling

In study III, MLM was used to investigate whether adolescents receiving SEdS in general classrooms differ in emotions from those receiving no SEdS at the individual level. Study III also investigated whether the proportion of students receiving SEdS at the classroom level had effects on the achievement emotions of students receiving no SEdS. This latter effect was considered to be a contextual effect—an effect of the classroom-level characteristics on students' outcomes, such as emotions (Marsh et al., 2009). The study used MLM models as they offer the opportunity to analyze both levels, individual (i.e., student) and classroom levels of the data simultaneously. All MLM models were estimated with the MLR in Mplus. These analyses are study-specific described in Section 6.3.

Specifically, MLMs generalize simple SEM models to circumstances in which there is a "nested" data structure (Marsh et al., 2009). A classic example is the observation of students within classrooms as in this study. However, the students who received SEdS in self-contained classrooms were not included in this analysis as they formed their own classes and were not nested in same general classrooms (Marsh et al., 2009).

In MLM, classroom-level variables are often based on the aggregation of individual-level variables. In the doubly latent multilevel models, latent individual-level variables, such as latent mathematics performance, were modeled as latent constructs at the classroom level, that is latent aggregation (Marsh et al., 2009). The doubly latent approach was used in this study because it accounted for measurement errors and sampling errors in the aggregation of variables to the classroom level (Marsh et al., 2009). Sampling error is due to assessing only a limited sample of students per classroom (Hoyle, 2012; Marsh et al., 2009). The models might contain manifest individual-level predictors, such as students receiving SEdS which were manifest aggregated at the classroom level, such as the proportion of SEdS students in classrooms (Marsh et al., 2009).

In MLM, the first fully unconditional models in which latent dependent variables (e.g., emotion) were defined at the individual and classroom levels were tested. In these models, the intraclass correlations (ICCs; Garson, 2013) that estimated the proportion of variance between classrooms were determined. Classroom-level analyses are warranted if the ICC is approximately 0.05 or higher (LeBreton & Senter, 2008). If this is warranted, the individual-level and classroom-level predictors will be added to these two levels.

Centering individual-level predictors is crucial in MLM (Enders & Tofighi, 2007; Lüdtke, Robitzsch, Trautwein, & Kunter, 2009). In the MLM, the individual-level predictors can be centered at the grand mean (i.e., adjusted to the mean of the variables in the whole sample) or at the group mean (i.e., adjusted to the mean of the cluster to which the student belongs; Enders & Tofighi, 2007). In the doubly latent model, researchers have suggested that indicators of the latent variables should be grand mean centered, causing independent effects at the classroom level (Marsh et al., 2009). Researchers have also suggested that individual-level dummy predictors (e.g., SEdS group and gender) should be group mean centered (Enders & Tofighi, 2007) to get independent effects at the classroom level.

As applying group mean centering to dummy variables yields the same interpretation as the continuous case (Enders & Tofighi, 2007), in this study this centering approach was used to determine contextual effects (Marsh et al., 2009). A parameter, the contextual effect, was constructed using the model constraint command in Mplus (Marsh et al., 2009). The contextual effect is present if the classroom-level effect is significantly different from the corresponding individual-level effect. This significant contextual effect indicates that the classroom-level characteristics are related to students' outcomes at the individual level (e.g., students' emotions) beyond what can be explained by individual characteristics.

Using random slope models in MLM, the cross-level interaction between individual- and classroom-level predictors can be determined (Marsh et al., 2009). This interaction reveals whether the strength of the classroom-level effect on individual-level characteristics varies across individuals (e.g., those receiving and not receiving SEdS).

6 Overview of original studies

The overall aim of the thesis was to examine the EF problems and mathematics-related achievement emotions among adolescents. The thesis consists of three empirical studies which investigated: 1) EF problems among adolescents with mathematics difficulties; 2) mathematics-related achievement emotions among adolescents with different performance levels; 3) mathematics-related achievement emotion among adolescents receiving special education support in general and self-contained mathematics classrooms and emotions among those receiving no special education support in more inclusive classrooms.

In this section, these studies will be briefly summarized and the main results of each original articles emphasized. The aims and method of the research will be briefly re-introduced, but more on a research-by-research basis. More information on participants, measures, procedures, and analysis is presented in Chapter 5. Further details are available in the original publications.

6.1 Study I

Holm, M. E., Aunio, P., Björn, P. M., Klenberg, L. Korhonen, J., & Hannula, M. S. (2018). Behavioral executive functions among adolescents with mathematics difficulties. *Journal of Learning Disabilities, 51*, 578–588. https://doi.org/10.1177/0022219417720684

6.1.1 Aims

The main aim of study I was to investigate various EF problems among adolescents with mathematics difficulties in relation to their mathematics classroom context. Adolescents with mathematics difficulties were compared to those with low mathematics performance and average or higher mathematics scores. This study also investigated gender differences in EF problems and the interaction effect of gender and mathematics performance groups on EF problems. This interaction effect indicated whether there are gender variations in EFs across mathematics performance groups (difficulties, low, and average or higher).

6.1.2 Participants and measures

In this study, the participants were 619 eighth graders (14–15 years old) with low and average mathematics performance at 27 compulsory schools. Adolescents were divided into groups with mathematics difficulties (*n* = 124), low mathematics performance (*n* = 140), and average or higher mathematics scores (*n* = 355).

Students' mathematics performance was assessed with the standardized paper-and-pencil KTLT test (Räsänen & Leino, 2005). The KTLT assesses performance in arithmetic, word problems, algebra, geometry, and unit conversion. In this study, the total score was used, and the reliability of this score was good ($\alpha = 0.83$).

EF problems were examined using the teacher-rated ATTEX (Klenberg et al., 2010). The ATTEX consists of 10 scales: distractibility, impulsivity, hyperactivity, directing attention, sustaining attention, shifting attention, initiative, planning, execution of action, and evaluation. The mean scores of the ATTEX scales were used as dependent variables. The reliability of the ATTEX scales ranged from good ($0.8 \leq \alpha < 0.9$) to excellent ($\alpha \geq 0.9$).

6.1.3 Data-analysis

Analysis of variance techniques (MANOVA and ANOVAs) and Scheffe post hoc tests were used to examine differences in EF problems between mathematics performance groups (see Section 5.3.2.1).

First, MANOVA was used to test the main effects of the mathematics performance groups, gender, and Group × Gender interaction on the multiple ATTEX at the same time. Second, if MANOVA was significant, separate ANOVAs were conducted to investigate the effects of the independent variables (performance groups, gender, and/or Gender × Group) on each ATTEX scales at a time. Third, Scheffe post hoc tests were used to compare the means of the mathematics performance groups on each ATTEX scales.

When statistical differences were found, the percentages of adolescents with scores on the ATTEX higher than +1 standard deviation were determined. The criterion (+1 *SD*) was based on a Finnish normative sample that presented typical EF problems in the classroom context in Finland (Klenberg et al., 2010). This comparison indicated the clinical perspective of the EF problems among adolescents with mathematics difficulties.

6.1.4 Results

Mathematics performance groups

The MANOVA revealed a significant main effect of the mathematics performance groups on the ATTEX. The ANOVAs showed that the performance groups had a significant effect on each ATTEX scale, with the exception of impulsivity and hyperactivity problems.

The post-hoc test revealed that adolescents with mathematics difficulties had significantly more problems with distractibility ($d = 0.35$), directing attention ($d = 0.48$), sustaining attention ($d = 0.34$), shifting attention ($d = 0.62$), initiative ($d = 0.53$), planning ($d = 0.52$), execution ($d = 0.49$), and evaluation ($d = 0.46$) than adolescents with average or higher scores. However, the differences in impulsivity or hyperactivity were not significant. The differences were highest between these groups in shifting attention, initiative, and planning problems.

Adolescents with mathematics difficulties had also significantly more problems with distractibility (*d* = 0.40), directing attention (*d* = 0.45), shifting attention (*d* = 0.35), initiative (*d* = 0.44), planning (*d* = 0.32), execution of action (*d* = 0.38), and evaluation (*d* = 0.32) than adolescents with low mathematics performance. However, the differences in impulsivity, hyperactivity, and sustaining attention were not significant. The highest differences were in distractibility, directing attention, and initiative problems between these groups.

The percentages of adolescents with mathematics difficulties who had scores higher than +1 standard deviation were 59% for distractibility, 55% for directing attention, 59% for sustaining attention, 74% for shifting attention, 65% for initiative, 62% for planning, 60% for execution of action, and 59% for evaluation.

Adolescents with low mathematics performance had significantly more problems with shifting attention (*d* = 0.26) than adolescents with average or higher mathematics scores, but the effect size for this difference was small. The percentage of adolescents with low mathematics performance with scores higher than +1 standard deviation was 59% for shifting attention.

Notably, Figure 1 in the original article illustrates these differences in the ATTEX scales among the mathematics performance groups. Additionally, the means and standard deviations in ATTEX for the mathematics groups were shown in Table 2 in the original article.

Gender

The main effects of gender on the ATTEX was significant. Males had significantly more problems than females on all EF problems among the overall sample when controlling for mathematics performance groups. The main effect of the Group × Gender interaction was not significant on the ATTEX. However, the gender differences on the all EF problems were negligible among adolescents with mathematics difficulties. Figure 1 in the original article illustrated these gender differences.

6.1.5 Summary of the results and conclusion

The findings of study I pointed out that adolescents with mathematics difficulties had more problems with several teacher-rated EFs than adolescents with average or higher scores. Adolescents with mathematics difficulties even have more problems with several EFs than those with low mathematics performance. The results also indicated that both females and males with mathematics difficulties have EF problems in mathematics.

However, adolescents with mathematics difficulties did not have more hyperactivity and impulsivity problems than other study groups, at according to their teachers. Additionally, adolescents with low mathematics performance showed only slightly more teacher-rated shifting attention problems than those with average or higher scores.

In conclusion, our results suggest that the comprehensive EF problems are the main future research topic among adolescents with mathematics difficulties. Both females and males with mathematics difficulties need practical methods to support their EF problems in their mathematics classrooms. Although adolescents with impulsivity and hyperactivity often take up teachers' attention, they do not need the most support in mathematics.

While the focus of this study was on the EF problems of adolescents struggling with mathematics, study II expanded the research to include their mathematics-related achievement emotions.

6.2 Study II

Holm, M. E., Hannula, M. S., & Björn, P. M. (2017). Mathematics-related emotions among Finnish adolescents across different performance levels. *Educational Psychology, 37*, 205–218. https://doi.org/10.1080/01443410.2016.1152354

6.2.1 Aims

The aim of study II was to investigate the differences in mathematics-related enjoyment, pride, anger, anxiety, shame, hopelessness, and boredom among adolescents with mathematics difficulties, low mathematics performance, and average or higher mathematics scores. In addition, this study investigated gender differences in emotions and the interactions between gender and mathematics performance groups on emotions. This interaction effect indicated whether there are gender variations in emotions across mathematics performance groups (difficulties, low, and average or higher).

6.2.2 Participants and measures

This study comprised 1,358 eighth-grade participants (14–15 years old) from 27 compulsory schools in Finland. Adolescents were classified into groups with mathematics difficulties (n = 136), low mathematics performance (n = 166), and average or higher mathematics scores (n = 1,056).

Students' mathematics performance was assessed with the standardized paper-and-pencil KTLT test (Räsänen & Leino, 2005). The KTLT assesses performance in arithmetic, word problems, algebra, geometry, and unit conversion. In this study, the total score was used and the reliability of this score was good (α = .89).

Mathematics-related achievement emotions were assessed using the AEQ-M (Pekrun et al., 2005). The AEQ-M is a student-reported measure that assesses seven typical achievement emotions, including enjoyment, pride, anger, anxiety, shame, hopelessness, and boredom, in relation to mathematics classroom, learning, and testing situations. The mean scores of the AEQ-M scales were used as dependent variables. The reliabilities of these scales ranged from good ($0.8 \leq \alpha < 0.9$) to excellent ($\alpha \geq 0.9$).

6.2.3 Data analysis

Analysis of variance techniques (MANOVA and ANOVAs) and post hoc tests were used to examine differences in mathematics-related achievement emotions between mathematics performance groups (see Section 5.3.2.1).

First, MANOVA was used to test the main effects of the mathematics performance groups, gender, and Group × Gender interaction on the multiple AEQ-M at the same time. Second, ANOVA analyses were conducted to investigate these effects (performance groups, gender, and Gender × Group) on each AEQ-M scale at a time. Third, Scheffe post hoc tests were used to compare the means of the mathematics performance groups on each AEQ-M scale.

6.2.4 Results

Mathematics performance group

MANOVA revealed that the performance group had a significant main effect on AEQ-M. The following ANOVAs showed that the performance groups had a significant effect on each AEQ-M scale.

The post-hoc test revealed that adolescents with mathematics difficulties reported more shame (d = 0.32) than adolescents with low mathematics performance. Adolescents with mathematics difficulties reported less enjoyment (d = –0.51) and pride (d = –0.67) and more anger (d = 0.48), anxiety (d = 0.56), shame (d = 0.60), and hopelessness (d = 0.65), but not more boredom than adolescents with average or higher scores.

Adolescents with low mathematics performance reported significantly less enjoyment (d = –0.54) and pride (d = –0.58) and more anger (d = 0.42), anxiety (d = 0.41), shame (d = 0.28), hopelessness (d = 0.51), and boredom (d = 0.28) than adolescents with average or higher scores. The effect sizes for boredom and shame were small. Notably, the means and standard deviations for the mathematics performance groups is presented in Table 3 in the original article.

Gender and interaction

MANOVA revealed that gender had significant main effects on the AEQ-M. The following ANOVAs showed that males reported more pride and enjoyment than females when controlling for mathematics performance groups. When performance groups were not controlled for, males reported more pride and enjoyment and less anxiety and hopelessness than females. However, the effect sizes for all these gender differences were small (Partial eta-squared = $\eta_p^2 \leq$ 0.01).

MANOVA revealed that the Performance Group × Gender had a significant main effect on the AEQ-M. The following ANOVAs showed that the interaction had significant effects on all AEQ-M scales.

Hence, the gender differences in all AEQ-M scales were investigated separately among the mathematics performance groups. Figure 1 in the original article illustrated these differences. This analysis revealed that females with mathematics difficulties reported less enjoyment ($\eta_p^2 = 0.13$) and pride ($\eta_p^2 = 0.10$) and more hopelessness ($\eta_p^2 = 0.05$) and boredom ($\eta_p^2 = 0.06$) than males with mathematics difficulties. In turn, males with low mathematics performance reported more anger ($\eta_p^2 = 0.05$), anxiety ($\eta_p^2 = 0.05$), shame ($\eta_p^2 = 0.04$), and boredom ($\eta_p^2 = 0.03$) than females with low mathematics performance. Females with average or higher scores reported more anxiety and hopelessness than males with average or higher scores, but the effect sizes were small ($\eta_p^2 = 0.01$).

Second, the differences in AEQ-M scales among the performance groups were investigated separately for males and females. Figure 2 in the original article illustrated these differences. For females, the main effects for performance groups in each AEQ-M scale were significant. Females with mathematics difficulties reported more shame ($d = 0.54$) and hopelessness ($d = 0.49$) than females with low mathematics performance. Females with mathematics difficulties reported less enjoyment ($d = -0.81$) and pride ($d = -0.92$) and more anger ($d = 0.52$), anxiety ($d = 0.53$), shame ($d = 0.62$), hopelessness ($d = 0.70$), and boredom ($d = 0.38$) than females with average or higher scores. Females with low mathematics performance reported only less pride ($d = -0.48$) and enjoyment ($d = -0.55$) than females with average or higher scores.

For males, the main effects for performance groups in each AEQ-M scale were significant. Males with low mathematics performance reported more boredom ($d = 0.54$) than males with mathematics difficulties. Males with low mathematics performance reported more anger ($d = 0.66$), anxiety ($d = 0.73$), shame ($d = 0.51$), hopelessness ($d = 0.83$), and boredom ($d = 0.54$), and less enjoyment ($d = -0.61$) and pride ($d = -0.60$) than males with average or higher scores. However, males with mathematics difficulties also reported more anger ($d = 0.42$), anxiety ($d = 0.57$), shame ($d = 0.55$), and hopelessness ($d = 0.55$) than males with average or higher scores, but differences in enjoyment, pride, and boredom were not significant.

6.2.5 Summary of the results and conclusion

Overall, the findings of study II indicate that adolescents with mathematics difficulties reported more shame than adolescents with low mathematics performance. Both adolescents with mathematics difficulties and with low mathematics performance reported less positive and more negative emotions than those with average or higher mathematics scores. However, the difference in boredom was negligible between these groups. The findings also revealed that mainly females with mathematics difficulties and males with low mathematics performance reported unpleasant emotions in mathematics.

In conclusion, our results suggested that mainly females with mathematics difficulties need support for their mathematics-related emotions, such as pride, enjoyment, and hopelessness. In turn, mathematical difficulties are less strongly related to mathematics-related achievement emotions among males. Males with low mathematics performance also need support for their mathematics-related emotions, such as anxiety, hopelessness, and anger. This study also revealed that students who experienced boredom in mathematics did not necessarily have mathematics difficulties.

While this study revealed that achievement emotions should be considered among adolescents struggling with mathematics, study III investigated whether these mathematics-related achievement emotions related to adolescents' special education support settings.

6.3 Study III

Holm, M. E., Björn, P. M., Laine, A., Korhonen, J., & Hannula, M. S. (2020). Achievement emotions among adolescents receiving special education support in mathematics. *Learning and Individual Differences, 79*. Advance online publication. https://doi.org/10.1016/j.lindif.2020.101851

6.3.1 Aims

The aim of study III was to investigate mathematics-related enjoyment, pride, anger, anxiety, shame, hopelessness, and boredom among adolescents in relation to special education support (SEdS) settings. Mathematics performance and gender were controlled for at the individual and classroom levels; and class size at the classroom level.

First, this study investigated whether adolescents receiving SEdS in self-contained mathematics classrooms differ in mathematics-related achievement emotions from those receiving SEdS in general classrooms and from those receiving no SEdS. Second, this study investigated whether adolescents receiving SEdS in general mathematics classroom differ in mathematics-related achievement emotions from those receiving no SEdS. Finally, this study examined whether the proportion of students receiving SEdS in general mathematics classrooms associated with mathematics-related emotions of adolescents receiving no SEdS.

6.3.2 Participants

The participants in study were 1,379 eighth-grade students (14–15 years old), distributed across 88 classes in 27 schools. For the aim of this study, adolescents were divided into adolescents receiving SEdS in self-contained mathematics classrooms (n = 73), adolescents received SEdS in general mathematics classrooms (n = 127), and adolescents receiving no SEdS (n = 1,179).

Students receiving SEdS in self-contained mathematics classrooms were taught in small, separate classrooms by special education teachers. Students receiving SEdS in general classrooms did so on a part-time (n = 100) or full-time basis (n = 27); these two groups did not differ significantly in mathematics-related achievement emotions. Teachers reported that students received part-time special education support for about one hour per week in small groups in resource rooms and otherwise, were in general classrooms (about three hours per week).

Additionally, emotions in general mathematics classrooms (n = 77) were investigated. Of the general classrooms, 44 were classrooms with students receiving SEdS (i.e., inclusive classrooms), and 33 were classrooms without any students receiving SEdS. On average, two students per class received SEdS in inclusive mathematics classrooms (minimum = one, maximum = ten).

6.3.3 Measures

Mathematics performance

The control variable, mathematics performance, was assessed with the standardized paper-and-pencil KTLT (Räsänen & Leino, 2005). The KTLT assesses performance in arithmetic, word problems, algebra, geometry, and unit conversion. Because latent models were used in this study, the mathematics performance was presented as a latent construct.

The latent mathematics performance construct was a one-factor model in which arithmetic, word problems, algebra, geometry, and unit conversion scales were indicators. The model fit of the latent mathematics performance was good (CFI > 0.98; RMSEA < 0.05; see Section 5.3.1.3).

Mathematics-related achievement emotions

Mathematics-related achievement emotions were assessed using the AEQ-M (Pekrun et al., 2005). The AEQ-M is a student-reported measure that assesses seven typical achievement emotions—enjoyment, pride, anger, anxiety, shame, hopelessness, and boredom—in relation to mathematics classroom, learning, and testing situations. In this study, latent achievement emotion constructs were used as dependent variables.

The model fits of these constructs were tested using CFA. Section 5.3.1.2 described this analysis method. Eight of the original 60 items were eliminated, as this analysis showed poor model fit for anxiety, shame, and pride (CFI < 0.88;

RMSEA > 0.10, see Section 5.3.1.3). After removing the eight items, the model fits for all emotions were acceptable (see ordinary article, Appendix A); and the reliabilities of the AEQ-M scales ranged from good ($0.8 \leq \alpha < 0.9$) to excellent ($\alpha \geq .9$). Notably, this removing is detailed described and justified in Section 2.2.1 in the original article.

6.3.4 Data analysis

Measurement invariance and SEM analysis

In the preliminary analysis, the measurement invariance across the three SEdS groups was first tested separately for each achievement emotion using the multiple-group CFA. Section 5.3.1.4 presented this testing procedures.

Next, SEM (see Section 5.3.2.2) was used to investigate whether adolescents receiving SEdS in self-contained mathematics classrooms differ in emotions from those receiving SEdS in general classrooms and from those receiving no SEdS. Mathematics performance and gender were controlled for. In SEM models, two dummy-coded SEdS groups (SEdS in general classrooms and no SEdS), the latent mathematics performance (the control variable), and the dummy-coded gender (the control variable) predicted each achievement emotion. The group receiving SEdS in self-contained classrooms was the reference group.

MLM analysis

Several MLMs (see Section 5.3.2.3) were used to investigate whether adolescents receiving SEdS in general mathematics classroom differ in emotions from those receiving no SEdS; and whether the proportion of students receiving SEdS in general mathematics classrooms associated with emotions of adolescents receiving no SEdS. Mathematics performance and gender were controlled for at the individual and classroom levels and class size at the classroom level.

All models were doubly latent types, in which latent individual-level achievement emotions (dependent variable) and mathematics performance (predictor) were modeled as latent constructs at the classroom level. The models also contained manifest individual-level predictors—SEdS group and gender—which were aggregated as the classroom-level predictors—gender proportion and proportion of SEdS students in classrooms.

First, fully unconditional models in which latent emotion constructs were defined at the individual and classroom levels were tested. To determine whether MLM was required, ICCs were determined for each emotion.

Second, in the main analysis, we specified the models in which the dummy coded SEdS group in general classrooms and gender (the control variable), and latent mathematics performance (the control variable) predicted each emotion at the individual level. The classroom-level predictors were the proportion of students receiving SEdS in general classrooms (varied between 0% to 57.14%), gender proportion, latent aggregated mathematics performance, and classroom size. The group receiving no SEdS was the reference group at the individual and classroom (aggregated) levels.

Indicators of the latent mathematics performance were grand mean centered in the doubly latent model; causing independent effects at the classroom level. The individual-level dummy predictors, including SEdS group and gender, were group-mean centered; causing independent effects at the classroom level. The contextual effect is present if the classroom-level effect of the proportion of students receiving SEdS is significantly different from the corresponding individual-level effect. This significant contextual effect indicates that the classroom-level proportion of students receiving SEdS is associated with students' emotions at the individual level beyond what can be explained by individual-level effects.

To test whether the effect of the proportion of SEdS is more related to students receiving no SEdS, a cross-level interaction effect between the proportion of students receiving SEdS at the classroom level and students receiving SEdS at the individual level were specified, using random-slope models. Because the contextual effects and random-slope models were based on unstandardized regression coefficients, only unstandardized regression coefficients are presented in the MLM results.

6.3.5 Preliminary and main results

Measurement invariance and SEM

As presented in the original article, latent emotions showed strong measurement invariance across the SEdS groups. Table 2 in the original article summarized this measurement invariance testing.

SEMs were used to investigate whether adolescents receiving SEdS in self-contained mathematics classrooms differ in emotions from other groups when mathematics performance and gender were controlled for. The SEM results were summarized in Table 4 in the original article. The results showed that adolescents receiving SEdS in general classrooms reported less enjoyment and pride and more anger, anxiety, shame, hopelessness, and boredom than those receiving SEdS in self-contained classrooms (in all cases $\beta \geq 0.17$). The highest differences were in pride ($\beta = -0.34$) and hopelessness ($\beta = 0.31$).

The results also showed that adolescents receiving no SEdS reported significantly less enjoyment and pride and more anger, anxiety, and hopelessness (in all cases $\beta \geq 0.10$) but not less shame and boredom than adolescents receiving SEdS in self-contained classrooms. The highest differences were in pride ($\beta = -0.23$). However, differences in emotions between those receiving SEdS in self-contained classrooms and those receiving no SEdS were negligible when mathematics performance and gender were not controlled for (See Appendix B in the original article).

MLM results

The unconditional multilevel models of each emotion all showed good model fit, and the composite reliabilities for the factors were good. The acceptable ICC (≥ 0.05) warranted analyses at the classroom level. Table 3 in the original article summarized these preliminary results.

MLMs were used to investigate emotions among adolescents in general classrooms when mathematics performance and gender were controlled for at the individual and classroom levels and class size at the classroom level. It should be noted that the MLM results were summarized in Table 5 in the original article.

At the individual level, the results revealed that students receiving SEdS in general classrooms reported less enjoyment and pride and more anger, anxiety, shame, hopelessness, and boredom than those receiving no SEdS (in all cases $b \geq 0.18$); the highest differences were in pride ($b = -0.49$) and hopelessness ($b = 0.43$). At the classroom level, the proportion of students receiving SEdS in general classrooms was significantly related to class-average enjoyment, pride, anger, anxiety, shame, hopelessness, and boredom.

The contextual effects on emotions were present if the effects of the classroom-level proportions of students receiving SEdS were significantly different from the corresponding individual-level effects; this was evident for anxiety, hopelessness, and boredom. Thus, adolescents reported more anxiety, hopelessness, and boredom in general classrooms when the proportion of adolescents receiving SEdS was higher.

The cross-level interaction effects (classroom-level proportion × individual-level SEdS group) on anxiety, hopelessness, and boredom were not significant. Hence, the contextual effects were evident among adolescents receiving no SEdS, but also among those receiving SEdS. Thus, the proportion of adolescents receiving SEdS in general classrooms related to anxiety, hopelessness, and boredom among students receiving no SEdS and receiving SEdS.

6.3.6 Summary of the results and conclusion

Study III investigated emotions among adolescents in general and self-contained mathematics classrooms when controlling for gender and mathematics performance at the individual and classroom levels and for classroom size at the classroom level. The findings show that adolescents receiving SEdS in self-contained mathematics classrooms reported more positive and less negative emotions than those receiving SEdS in general classrooms.

The findings also indicated that adolescents receiving SEdS in self-contained mathematics classroom reported even more positive and less negative emotions but not less shame and boredom than those receiving no SEdS. Notably, differences in emotions between these two groups were negligible when mathematics performance and gender were not controlled for. This is reasonable because adolescents receiving special education support in self-contained classrooms had low mathematics performance and this low performance affected their emotions negatively.

Contrarily, the findings revealed that adolescents receiving SEdS in general classrooms reported fewer positive emotions and more negative emotions than those receiving no SEdS. Even adolescents receiving no SEdS reported more anxiety, hopelessness, and boredom when proportions of adolescents receiving SEdS were higher in general classrooms.

To conclude, inclusion in general classrooms may not be fully functional for supporting the achievement emotions of adolescents receiving and not receiving SEdS. Thus, to implement global inclusion, educators should develop practical solutions that support achievement emotions in inclusive classrooms.

7 Summary of the main findings

Table 13 summarizes the main findings of the three original studies used in this dissertation. Next, some of these findings will be discussed. These findings revealed that adolescents with mathematics difficulties had more problems with several teacher-rated behavioral EFs and reported several unpleasant mathematics-related achievement emotions than those with average or higher mathematics scores. However, difference in hyperactivity, impulsivity, and boredom were not significant. When compared to those with low mathematics performance, adolescents with mathematics difficulties had even more problems with several EFs, except hyperactivity, impulsivity, and sustaining attention, and they reported more shame. Additionally, adolescents with low mathematics performance had only more shifting attention problems, but they also reported more unpleasant emotions than those with average or high scores.

Although this study showed that males had more teacher-rated behavioral EF problems than females, differences were negligible among adolescents with mathematics difficulties. Hence, considering EF problems among females and males with mathematics difficulties is critical. This study also revealed that females reported only less pride and enjoyment than males when controlling for mathematics performance groups. However, the significant interaction effect indicated that mainly females with mathematics difficulties reported unpleasant emotions, such as low pride and enjoyment, and high hopelessness and shame. Additionally, mainly males with low mathematics performance reported negative emotions such as high anger, anxiety, and hopelessness.

This study also investigated emotions among adolescents in self-contained and general classrooms when controlling for mathematics performance, gender, and class size. Importantly, the results revealed that adolescents receiving special education support in self-contained mathematics classrooms reported more positive emotions and fewer negative emotions than those receiving special education support in general classrooms. In addition, adolescents receiving no special education support reported more boredom, anxiety and hopelessness in general classrooms when the proportion of students receiving special education support was higher. Hence, inclusion in general classrooms does not support adolescents' mathematics-related achievement emotions enough. Next, these results are discussed in relation to the empirical background (see Section 8) and the theoretical background (Section 9).

Table 13. Summary of the main findings

	Math difficulties	**Low math performance**	**Gender**
I	-More EF problems in comparison to those with average or higher scores, except impulsivity or hyperactivity; mainly shifting attention, initiative, and planning problems -More EF problems in comparison to those with low math performance, except impulsivity, hyperactivity, and sustaining attention; mainly distractibility, directing attention, and initiative problems	-More shifting attention problems in comparison to those with average or higher scores	-Males have more problems than females with all EFs in whole sample -Both females and males with math difficulties have EF problems
II	-More unpleasant emotions in comparison to those with average or higher scores, except boredom; mainly more hopelessness and shame and less pride -More shame in comparison to adolescents with low math performance	-More unpleasant emotions in comparison to those with average or higher scores; differences in boredom and shame were negligible	-Females reported less pride and enjoyment than males when controlling for math groups -Females with math difficulties reported unpleasant emotions; like low pride and enjoyment and high hopelessness and shame -Males with low math performance reported negative emotions; like high anxiety, anger, and hopelessness
	Special education support in self-contained classes	**Special education support in general classes**	**No special education support**
III[a]	-More pleasant emotions in comparison to those receiving special education support in general classes; mainly more pride and less hopelessness -More enjoyment and pride and less anger, anxiety, and hopelessness in comparison to those receiving no support	-More negative emotions in comparison to those receiving no support; mainly less pride and more hopelessness	-More anxiety, hopelessness, and boredom when the proportion of those receiving special education support in inclusive classes is higher

Note. [a]Mathematics performance, gender, and class size were controlled for when relationships between special education support and emotions were investigated. Studies I-III.

8 Discussion of the main results

The present study investigated behavioral EFs and mathematics-related achievement emotions among adolescents. As Figures 11 to 13 show (red lines), this study substantially expands the empirical background. Next, these extensions will be described systematically, and a more study-specific discussion of the three studies is presented in the published articles (I–III).

8.1 Executive functions and emotions among adolescents with different math levels

The present study investigated teacher-rated behavioral EF problems and self-reported mathematics-related achievement emotions among adolescents with mathematics difficulties and low mathematics performance. Figure 11 summarizes previous empirical results (*links 1–6*) and the results of this present dissertation (*links A–F*).

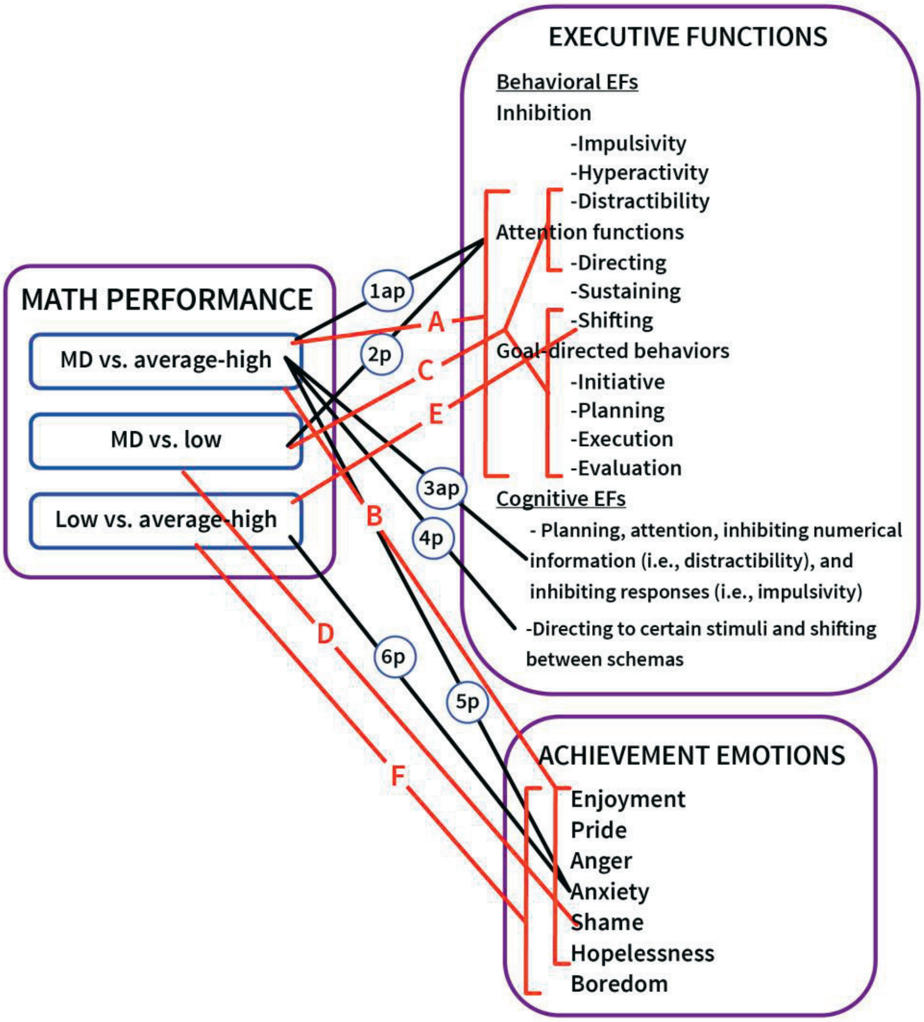

Figure 11. Present and previous results of the relationships between mathematics groups and EFs and mathematics groups and achievement emotions. EFs = executive functions; MD = mathematics difficulties; Low = low mathematics performance; average-high = average or higher mathematics scores; p = found in primary school; ap = found among adolescents and in primary school; links 1–6 = previous results; links A–F = present results.

8.1.1 Mathematics difficulties vs. average or higher mathematics performance

Specifically, the results of the present study contribute the previous findings that adolescents with mathematics difficulties have more teacher-rated attention problems (*link 1*; Swanson, 2012) and primary school children with mathematics difficulties reported more anxiety than those with average or higher mathematics scores (*link 5*; Passolunghi, 2011; Wu et al., 2014). In addition to attention problems and anxiety, this study revealed that adolescents with mathematics difficulties had more problems with several teacher-rated EFs (*link A*) and self-reported several unpleasant mathematics-related achievement emotions (*link B*) in comparison to those with average or higher scores. However, the differences in hyperactivity, impulsivity, and boredom were not significant. The greatest differences were in shifting attention, planning, and initiative, as well as shame, pride, and hopelessness.

While previous studies have found that adolescents with mathematics difficulties had more problems with cognitive tasks measuring planning, attention, and inhibiting numerical information (i.e., distractibility) than those with average or higher scores (*link 3*; Cai et al., 2013), this study revealed that adolescents with mathematics difficulties also demonstrate EF problems in their mathematics classroom behaviors.

Notably, this study revealed that 74% of adolescents with mathematics difficulties had more problems with teacher-rated shifting attention than Finnish students in general. This extends previous findings that primary school children with mathematics difficulties have more problems with complex cognitive tasks measuring shifting between schemas than those with average or higher mathematics scores (*link 4*; McLean & Hitch, 1999; van der Sluis et al., 2004), but not with easier cognitive tasks measuring shifting attention (Raghubar et al., 2009; van der Sluis et al., 2004). These studies suggested that problems with shifting attention behavior and with complex cognitive shifting are critical among students with mathematics difficulties.

However, these results are not in line with findings by Clark and colleagues (2010) that indicated an insignificant relation between teacher-rated shifting attention behaviors and mathematics performance in preschool. Perhaps shifting attention problems are more typical among older students when more complex problem-solving skills are required and developed (Anderson, 2002; Bull & Devine, 2014).

Although anxiety is often seen as a central emotion in mathematics difficulties (Passolunghi, 2011; Wu et al., 2014), this study suggests that various mathematics-related achievement emotions should be considered among adolescents with mathematics difficulties, particularly shame, hopelessness, and pride.

Interestingly, the present study also revealed that adolescents with mathematics difficulties did not have more problems with impulsivity and hyperactivity than those with average or higher mathematics scores, at least in their teachers' view. Contrarily, the previous results indicated that adolescents with mathematics difficulties have more problems in cognitive tasks measuring the ability to inhibit responses, referring to impulsivity, than those with average or higher mathematics scores (*link 3*; Cai et al., 2013; Swanson, 2012). Taken together these studies suggest that behavioral impulsivity differs from cognitive impulsivity.

However, previous results also indicated that students with mathematics difficulties have more problems with cognitive tasks requiring working memory (Swanson, 2012) and inhibiting irrelevant numerical stimuli (Szűcs et al., 2013) than impulsivity control, supporting the findings of the present study that impulsivity is not as central among students with mathematics difficulties.

Additionally, the results of this study expand the earlier findings that teacher-rated hyperactivity and/or impulsivity behaviors in primary school are not strongly related to mathematics performance (Merrell & Tymms, 2001). The present study suggests that this is also evident among adolescents with mathematics difficulties.

In addition to hyperactivity and impulsivity, this study revealed that adolescents with mathematics difficulties did not report more boredom than those with average or higher mathematics scores. Hence, the present work supports the control-value theory (Pekrun, 2006) and empirical evidence (Acee et al., 2010; Daschmann, Goetz, & Stupnisky, 2011) that boredom might occur when mathematics activities are monotonous, meaningless, and either too challenging or unchallenging. Hence, both low and high performing students might also report boredom.

8.1.2 Mathematics difficulties vs. low mathematics performance

This study extends previous findings that primary school students with mathematics difficulties have more problems with teacher- and parent-rated attention behaviors than those with low mathematics performance (*link 2*; Raghubar et al., 2009; Wu et al., 2014). Adolescents with mathematics difficulties were found to have more problems with several teacher-rated behavioral EFs, except impulsivity, hyperactivity, and sustaining attention, in comparison to adolescents with low mathematics performance (*link C*). Differences were highest in distractibility, directing attention, and initiative problems between these two low-performing groups.

However, the present results conflict with findings by McGlaughlin and colleagues (2005) that adolescents with mathematics difficulties did not self-report more attention problems than those with low mathematics performance. In that study, adolescents self-reported attention problems; and attention problems included hyperactivity and impulsivity behaviors (McGlaughlin et al., 2005). Indeed, the reliability of self-reported inattention and hyperactivity behaviors might be lower than teachers' ratings (Du, Kou, & Coghill, 2008). Additionally, hyperactivity and impulsivity do not necessarily relate to mathematics performance (Merrell & Tymms, 2001). These two issues might explain these conflicting results.

Indeed, the present study revealed that differences in teacher-rated hyperactivity, impulsivity, and sustaining attention problems were not significant between the groups with mathematics difficulties and low mathematics performance. These findings support the previous suggestion that hyperactivity and impulsivity are not central behaviors among adolescents with mathematics difficulties.

Although the present study indicated that several behavioral EF problems differentiate students with mathematics difficulties from those with low mathematics performance, shame was the only achievement emotion that adolescents with mathematics difficulties reported more than those with low mathematics performance (*link D*). This study supports Wu and colleagues' (2014) findings that primary school children with mathematics difficulties did not report more anxiety than those with low mathematics performance. The present work suggests that the experience of shame rather than oft-studied anxiety (Ashcraft & Krause, 2007; Else-Quest et al., 2010; Passolunghi, 2011; Wu et al., 2014) should be included in the research on mathematics difficulties.

While previous studies have found that students with mathematics difficulties differ in cognitive abilities, such as working memory abilities, from those with low mathematics performance (Geary et al., 2008; Mazzocco, 2008), this study indicates that this is also evident for several behavioral EFs and shame.

8.1.3 Low mathematics performance vs. average or higher mathematics performance

This study expands previous findings that adolescents with low mathematics performance did not have more problems with parent-rated attention behaviors but self-reported more anxiety than those with average or higher mathematics scores (*link 6*; Wu et al., 2014). The present study revealed that adolescents with low mathematics performance showed only slightly more teacher-rated shifting attention problems (*link E*) but reported more unpleasant mathematics-related achievement emotions than those with average or higher mathematics scores (*link F*).

However, this study revealed that differences in boredom and shame were only marginally significant, indicating that mathematically low performing adolescents did not necessarily experience more boredom or shame than those with average or higher scores.

8.1.4 Explanations for the present results regarding executive function problems and emotions

The present study raises the question why primarily adolescents with mathematics difficulties had teacher-rated EF problems, while several unpleasant emotions were reported by adolescents with mathematics difficulties and low mathematics performance. However, this study also revealed that primarily adolescents with mathematics difficulties reported shame.

Executive functions

The theoretical framework states that EFs influence mathematics performance (Geary, 2004). Hence, EF problems might lead to mathematics difficulties. Specifically, researchers suggested that EFs are needed in mathematical problem solving and learning (Bull & Lee, 2014; Fuchs et al., 2006; Geary, 2004). For example, the inability to inhibit prepotent responses (i.e., distractibility) may suppress the use of information from a word problem that is irrelevant to the solution and shifting attention problems may suppress switching between mathematical operations (Bull & Lee, 2014). Fuchs et al. (2006) also suggested that behavioral EF problems, particularly attention problems, might lead to a decrease in students' opportunity to persevere with mathematics tasks.

It is also suggested that instruction may fail to address the needs of students with EF problems (Desoete, 2009; Fuchs et al., 2006) and thus their difficulties in mathematics might become more severe. Desoete's (2009) findings indicate that it was often not a matter of students being able to perform in mathematics, but rather of not succeeding under time-limited conditions, requiring unreasonable effort to start tasks, and being less certain.

Although the theoretical link is stated to be between EFs and mathematics performance (Geary, 2004), it can also go the other direction (Fuchs et al., 2006). Specifically, students with mathematics difficulties might have problems with EFs in the context of mathematics learning, such as planning and initiative for tasks, because of their low mathematics abilities.

In addition, Fuchs et al. (2006) suggested that students' mathematics difficulties might affect teachers' ratings of behavioral EFs. However, the present results indicate that there were adolescents with mathematics difficulties whose teachers did not consider them to have EF problems (e.g., hyperactivity) and vice versa. One might also argue that a reason why shifting attention problems were found to be typical for those with mathematics difficulties and low mathematics performance is that teachers are better at identifying these problems compared with other EF problems. However, the teacher did not rate hyperactivity and impulsivity behaviors among adolescents struggling with mathematics, although hyperactivity and impulsivity might be quite prominent behaviors in the classroom.

Emotions

This study also found that both adolescents with mathematics difficulties and those with low mathematics performance reported unpleasant mathematics-related achievement emotions. The control-value theory states that there is a reciprocal relationship between academic performance and achievement emotions (Pekrun, 2006; Pekrun et al., 2007). Other researchers have also noted that the relationship between mathematics performance and anxiety is reciprocal (Carey et al., 2016).

According to the control-value theory, adolescents' unpleasant emotions might harm their learning processes—cognitive resources, motivation, use of strategies, and self-regulation—and thus also cause difficulties and low performance in mathematics. In turn, students' difficulties in mathematics and low mathematics performance might reduce their perceived control and value in mathematics and thus cause unpleasant mathematics-related achievement emotions (Pekrun, 2006). This study suggested that this reciprocal relationship might be evident among adolescents with mathematics difficulties and low mathematics performance.

This study also revealed that shame was mainly characteristic among those with mathematics difficulties. According to the control-value theory (Pekrun, 2006), students with mathematics difficulties might perceive that they have caused their failure and hence report shame particularly. According to this theory, shame might also harm their learning processes and deepen their mathematics difficulties. Other researchers have also stated that shame is associated with perceptions of failure, which might result from an individual's own characteristics, such as low abilities (Lewis, 2003; Weiner, 2014). Moreover, students who experience shame often make less effort to improve their performance (Oades-Sese, Matthews, & Lewis, 2014).

8.2 Executive functions and emotions among females and males

Another aim of the present study was to investigate whether EF problems and mathematics-related achievement emotions differ according to gender. Figure 12 summarizes previous results (*links 7–11*) and the results of this present study (*links G–J*).

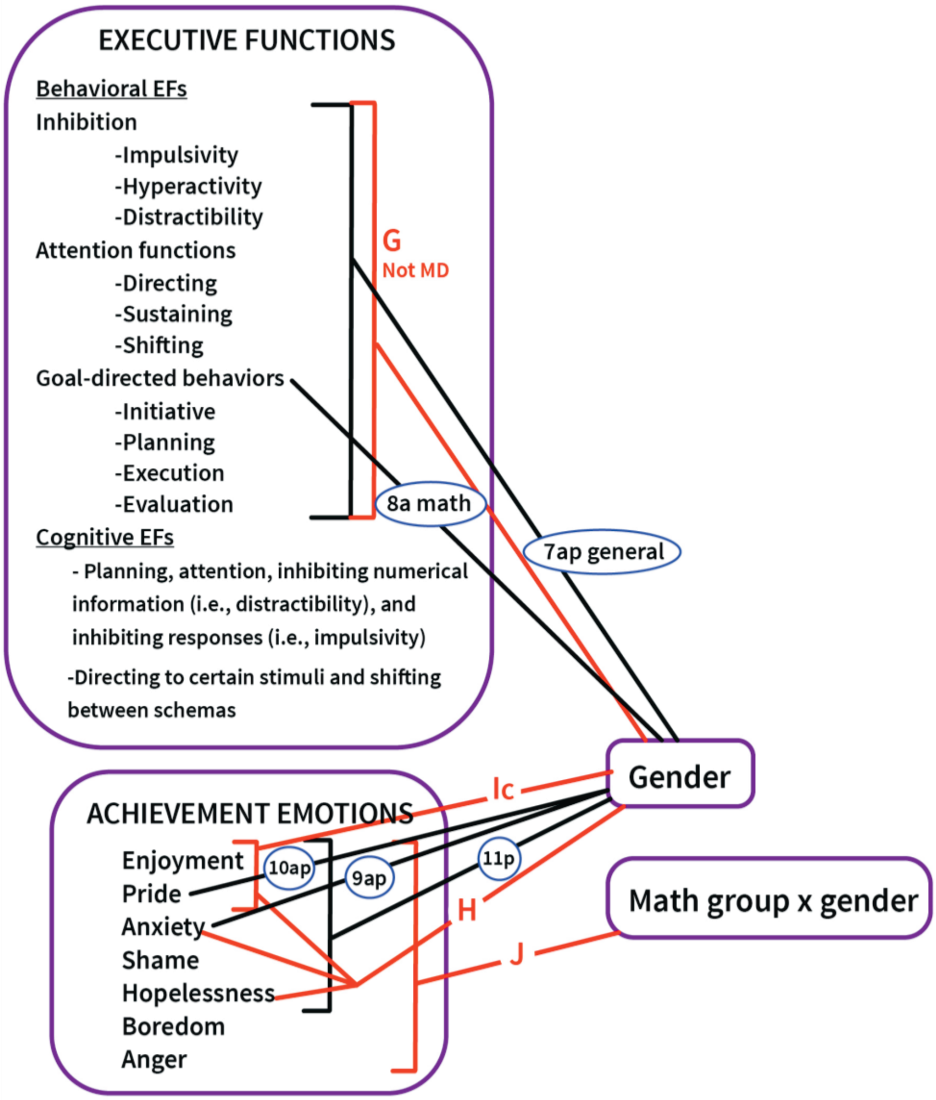

Figure 12. Present and previous results of the EFs and achievement emotions among females and males. EFs = executive functions; MD = mathematics difficulties; math group x gender = interaction between mathematics performance groups and gender; a = found among adolescents; p = found in primary school; ap = found among adolescents and in primary school; c = controlling for mathematics performance groups; links 7–11 = previous results; links G–J = present results.

The present study supports the previous findings that males showed more teacher-rated behavioral EF problems in general than females (*link 7*; Dobbs et al., 2006; Huizinga & Smidts, 2011 Klenberg et al., 2010; Merrell & Tymms, 2001). The present study also supports previous results that males had more problems with self-reported goal-directed behaviors in mathematics than females (*link 8*; Cleary & Chen, 2009; Kenney-Benson et al., 2006). This study found these gender differences in several teacher-rated behavioral EF problems in mathematics (*link G*).

Some earlier studies found that males showed more problems in cognitive tasks measuring planning and attention than females (Naglieri & Rojahn, 2001; Sussman & Tasso, 2013). In turn, other studies found no significant gender differences in cognitive tasks measuring planning, attention, and inhibiting responses or irrelevant stimulus (Cai et al., 2013). Hence, these cognitive and behavioral studies together suggest that differences in EFs might be more evident at the behavioral level than the cognitive level.

This study also extends Wu et al.'s (2014) findings that females struggling with mathematics might also have parent-rated attention problems. The present study indicates that gender differences in teacher-rated behavioral EF problems were not significant among adolescents with mathematics difficulties. Hence, females with mathematics difficulties also tended to have several behavioral EF problems in their mathematics classrooms.

Although previous studies have constantly found that females reported more anxiety than males (*link 9*; Devine et al., 2012; Else-Quest et al., 2010; Miller & Bichsel, 2004; OECD, 2004), the present study revealed that females only reported more anxiety and hopelessness, as well as less pride and enjoyment than males when mathematics performance was not controlled for (*link H*). This study also revealed that females only reported less pride and enjoyment than males when mathematics performance was controlled for (*link Ic* [controlled link]). Hence, this study indicates that females might experience less pride and enjoyment despite their mathematics performance.

This study supported Stipek and Gralinski's (1991) findings that female adolescents reported less pride (*link 10*), but not more shame than males. Together, these studies suggest that pride is characteristic among males in mathematics. This study did not fully support Frenzel et al.'s (2007) findings that females in primary school reported less mathematics-related enjoyment and pride and more anxiety, shame, and hopelessness than males when mathematics performance was controlled for (*link 11*). Taken together these studies suggest that gender differences in mathematics-related achievement emotions are smaller among adolescents.

The present study also found a significant interaction effect between gender and mathematics performance groups in all measured mathematics-related achievement emotions (*link J*). This interaction effect indicated that there are gender variations in emotions across mathematics performance groups. These findings conflict with hypothesis (H6) and Wu et al.'s results that the interaction effect between gender and mathematics performance groups on anxiety is insignificant. However, Wu et al. (2014) focused on a small primary school sample, meaning the interaction effect might not reach significance.

The significant interaction found in this study revealed that mainly females with mathematics difficulties reported unpleasant mathematics-related achievement emotions. Specifically, females with mathematics difficulties reported less enjoyment and pride and more hopelessness and boredom than males with mathematics difficulties; more shame and hopelessness than females with low mathematics performance; and more unpleasant achievement emotions than females with average or higher mathematics performance. While Frenzel et al. (2007a) found that females in primary school reported more hopelessness and less pride and enjoyment in the overall population, the present study suggests that these gender differences become apparent among adolescents with mathematics difficulties.

In turn, the significant interaction found in this study revealed that mainly males with low mathematics performance reported unpleasant emotions. More precisely, males with low mathematics performance reported more anger, anxiety, shame, and boredom than females with low mathematics performance; more boredom than males with mathematics difficulties; and more unpleasant emotions than males with average or higher scores. Although previous research has constantly revealed that females reported more negative emotions, such as anxiety, than males in mathematics (Else-Quest et al., 2010; Frenzel et al., 2007a; OECD, 2004; Stipek & Gralinski, 1991), the present findings revealed that this is not evident among adolescents with low mathematics performance.

However, the present study also revealed that males with mathematics difficulties reported more anger, anxiety, shame, and hopelessness than males with average or higher scores, but these differences were smaller (according to the effect sizes) than the differences between males with low mathematics performance and with average or higher scores.

In summary, the present study suggests that primarily pride, enjoyment, hopelessness, and shame should be considered among females with mathematics difficulties, while primarily anger, anxiety, and hopelessness should be considered among males with low mathematics performance and males with mathematics difficulties.

8.2.1 Explanations for the present results regarding gender

The present work raises the question of why both females and males tended to have teacher-rated behavioral EF problems and why females with mathematics difficulties and males with low mathematics performance mainly reported unpleasant mathematics-related achievement emotions.

Although behavioral problems are often seen as a way for males to react, the present study revealed that females with mathematics difficulties also had EF problems. Hence, both females and males might have behavioral EF problems that might harm their mathematics performance and cause their mathematics difficulties (Geary, 2004; Bull & Lee, 2014). Nevertheless, the present study also found that males had more teacher-rated behavioral EF problems than females among the whole sample, meaning males might have EF problems despite they do not have mathematics difficulties.

In addition to behavioral EF problems, this study indicated that females with mathematics difficulties reported unpleasant mathematics-related achievement emotions. Perhaps females with mathematics difficulties might be at risk of being judged by the stereotype that they are weaker in mathematics than males (Osborne, 2007; Spencer, Steele, & Quinn, 1999), and this stereotype might reduce their perceived control and value in mathematics and they might experience unpleasant emotions, including low levels of enjoyment and pride and high levels of shame and hopelessness (Pekrun, 2006). Females with mathematics difficulties might also perceive teachers' negative feedback as diagnostic (Roberts, 1991) and show concern that they have not gained the approval of their teachers when they fail (Pomerantz, Altermatt, & Saxon, 2002); thus, they might report unpleasant achievement emotions (Pomerantz et al., 2002).

As mathematics is stereotyped as a male domain (Spencer et al., 1999), perhaps males with low mathematics performance who are just below average performance perceive that they should be better at mathematics and thus mainly reported unpleasant mathematics-related achievement emotions, such as anxiety, hopelessness, and anger. Males with low mathematics performance might also perceive that they can control their mathematics performance, but other factors caused (e.g., poor teaching) their failure and thus reported anger in particular (Pekrun, 2006).

The present study also indicates that males with mathematics difficulties often demonstrate behavioral EF problems rather than reported unpleasant achievement emotions. Specifically, the present study revealed that males with mathematics difficulties did not differ in enjoyment, pride, and boredom from males with average or higher mathematics scores. Perhaps males with mathematics difficulties have less pressure to perform well and meet the requirements in mathematics and therefore reported such pleasant emotions. Willcutt and Pennington (2000) suggested that males with difficulties are identified more frequently by parents and teachers as in need of attention and support, as they might act in a disruptive manner. Perhaps this attention and support cause adolescents with mathematics difficulties to report more pleasant emotions.

Notably, males with mathematics difficulties still reported more anger, anxiety, shame, and hopelessness than those with average or higher scores, suggesting a link still exists between mathematics difficulties and such emotions among males.

8.3 Special education support and achievement emotions

The present work also investigated adolescents' mathematics-related achievement emotions in inclusive and self-contained mathematics classrooms. Notably, this study controlled for gender and mathematics performance at the individual and classroom levels and for classroom size at the classroom level. Figure 13 summarizes previous results (*links 12–18*) and the results of this present study (*links K–N*).

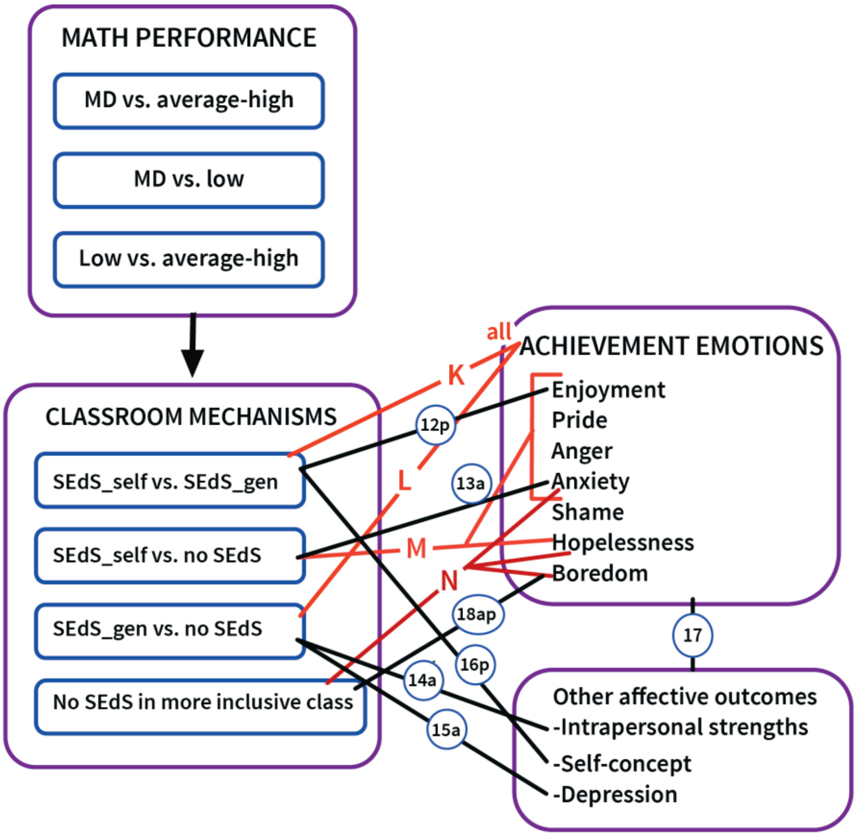

Figure 13. Present and previous results of the relationships between special education support and achievement emotions. MD = mathematics difficulties; Low = low mathematics performance; average-high = average or higher mathematics scores; SEdS_self = receiving special education support (SEdS) in self-contained classrooms; SEdS_gen = receiving SEdS in general classrooms; a = found among adolescents; p = found in primary school; ap = found among adolescents and in primary school; links 12–18 = previous results; links K–N = present results.

The study revealed that students receiving special education support in self-contained classrooms reported more enjoyment and pride and less anger, anxiety, shame, hopelessness, and boredom than those receiving special education support in general classrooms (*link K*: all emotions). Hence, the present results extend previous findings that primary school students receiving special education support in self-contained classrooms reported more enjoyment (*link 12*) and lower self-concept (*link 16*) than those receiving special education support in general classrooms (Kocaj et al., 2018). This study found that this is evident for several achievement emotions.

The present study also extends Wiest et al.'s (2001) findings that adolescents receiving special education support in self-contained classrooms report less mathematics-related anxiety than those receiving no special education support (*link 13*). This study found that adolescents receiving special education support in self-contained classrooms reported less anxiety, but also less anger and hopelessness and more enjoyment and pride than those receiving no special education support (*link M*) when controlling for mathematics performance and gender. Notably, these differences in emotions between these two groups were negligible when mathematics performance and gender were not controlled for (See Appendix B in the original article). This is understandable because adolescents receiving special education support in self-contained classrooms had low mathematics performance and this low performance affected negatively their emotions.

In turn, this study revealed that adolescents receiving special education support in general classrooms reported less enjoyment and pride and more anxiety, anger, hopelessness, shame, and boredom than those receiving no special education support (*link L*: all emotions). Hence, the present work extends previous results that adolescents receiving special education support in general classrooms reported more negative affective outcomes—less intrapersonal strength (*link 14*) and more depression (*link 15*)—than those receiving no special education support (Lappalainen et al., 2009; Valås, 2001). The present study was the first to show these differences in various mathematics-related achievement emotions.

The present study also indicated that also those receiving no special education support might experience negative emotions in more inclusive classrooms. Specifically, the present work revealed that adolescents receiving no special education support reported more boredom, anxiety, and hopelessness in inclusive classrooms when the proportion of students receiving special education support was higher (*link N*). The present work extends the previous findings that in interviews, students receiving no special education support reported experiencing boredom in inclusive classrooms (*link 18*; Litvack et al., 2011; Vaughn et al., 1995). However, this study further revealed that adolescents receiving special education support also reported anxiety, hopelessness, and boredom in more inclusive classrooms. Hence, all adolescents might need emotional support in inclusive mathematics classrooms.

8.3.1 Explanations for the present results regarding special education support

The present findings raise the question of why those receiving special education support in general classrooms reported several unpleasant mathematics-related achievement emotions and those receiving special education support in self-contained classrooms reported the opposite. The present findings also raise the question of why adolescents receiving no special education support reported anxiety, hopelessness, and boredom in more inclusive classrooms. Notably, the effects of the gender, mathematics performance, and class size were controlled for.

The BFLPE might be one reason for the differences in achievement emotions among the study groups—adolescents receiving special education support in self-contained and general classrooms and those receiving no such support. According to the BFLPE (Kocaj et al., 2018; Pekrun et al., 2019), adolescents receiving special education support in general classrooms might experience more unpleasant achievement emotions than other study groups, as they study and compare themselves with their higher-performing classmates. Contrarily, adolescents receiving special education support in self-contained classrooms might report more pleasant emotions than other study groups because they compare themselves with lower-performing classmates.

Furthermore, adolescents receiving special education support in small, self-contained classrooms might be subjected to expectations, receive instructions, and be assigned tasks and goals that match their capabilities, as well as receive personal support and positive feedback. Thus, according to the control-value theory (Pekrun, 2006), they might report more pleasant mathematics-related achievement emotions than other study groups. As these supportive classroom mechanisms might not be comprehensively implemented in general mathematics classrooms, adolescents receiving special education support in such classrooms might, in turn, report more unpleasant mathematics-related achievement emotions than other study groups.

But why did adolescents receiving no special education support also report negative emotions in more inclusive classrooms? Adolescents receiving no special education support might report boredom, as the learning demands might be lower in more inclusive classrooms and they might not be assigned enough valuable and challenging mathematics activities in such classrooms (Litvack et al., 2011; Ruijs et al., 2010). The control-value theory, indeed, states that boredom is related to valueless, unchallenging, and challenging mathematics activities (Pekrun, 2006).

In addition, teachers might not have enough time to support adolescents receiving no special education support in more inclusive classrooms because students receiving special education support take the teachers' attention (Ahmed et al., 2010; Dyson et al., 2004; Sakiz et al., 2012). Hence, adolescents receiving no special education support might report more hopelessness and anxiety in such inclusive classrooms.

The present study also indicates that adolescents receiving special education support reported more anxiety, hopelessness, and boredom in more inclusive classrooms. The decreased support in more inclusive classrooms might also explain these findings. Specifically, learning without support might be challenging and lead to failure among adolescents receiving special education support; as such, they may report boredom, hopelessness, and anxiety (Pekrun, 2006; Sakiz et al., 2012). Notably, the control-value theory states that boredom is also associated with challenging activities (Pekrun, 2006).

9 Theoretical implications

Figure 14 demonstrates how this study supports or extends the theoretical model. The main links found in this study are shown in red in this Figure. Next, these links are discussed in detail.

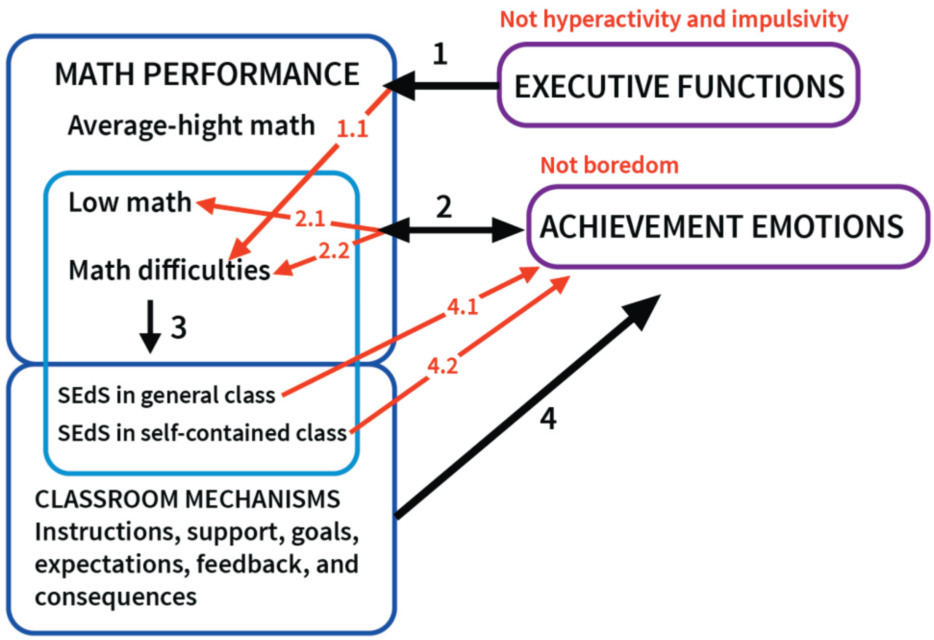

Figure 14. The extended theoretical model. SEdS = special education support; average-high math = average or higher mathematics scores.

First, this study supports the theoretical framework that it is critical to differentiate students with mathematics difficulties from those with low mathematics performance and those with average or higher mathematics scores (Geary et al., 2008; Mazzocco, 2008) when investigating adolescents' behavioral EFs and mathematics-related achievement emotions. This study found that adolescents with mathematics difficulties had several EF problems and reported more shame than those with low mathematics performance and average or higher mathematics scores. In turn, adolescents with low mathematics performance did not necessarily have EF problems or report shame.

Based on Geary's (2004) hierarchical framework, there is a theoretical relationship (*link 1*) between EFs and mathematics performance. This dissertation confirms this link and showed that mainly adolescents with mathematics difficulties have problems with several EFs (*link 1.1*). As this study found that adolescents with low mathematics performance have only shifting attention problems, this study suggests that this *link 1* is strongest among adolescents with mathematics difficulties.

Because the present results revealed that students with mathematics difficulties did not have hyperactivity and impulsivity problems when compared to those with average or higher mathematics scores or those with low mathematics performance, this study also suggests that *link 1* would not be central between mathematics performance and hyperactivity or impulsivity.

The control-value theory states that there is a reciprocal relationship (*link 2*) between academic performance and mathematics-related achievement emotions (Pekrun, 2006; Pekrun et al., 2007). This dissertation confirms this link and shows that adolescents with low mathematics performance (*link 2.1*) and mathematics difficulties (*link 2.2*) reported experiencing fewer positive and more negative emotions than those with average or higher mathematics scores.

The present study also found that adolescents with mathematics difficulties did not report more boredom than those with average or higher mathematics scores and differences in boredom were negligible between those with low mathematics performance and those with average or higher mathematics scores. Hence, this study also suggests that *link 2* would not be central between mathematics performance and boredom.

Because the present results indicated that primarily adolescents with mathematics difficulties reported experiencing shame when compared to other mathematics performance groups, this study also suggests that shame is particularly linked to mathematics difficulties (*link 2.2*).

As this study revealed that primarily females with mathematics difficulties and males with low mathematics performance reported unpleasant emotions, this study suggests that the link between mathematics difficulties and emotions (*link 2.2*) is mainly evident among females, while the link between low mathematics performance and emotions (*link 2.1*) is mainly evident among males.

The control-value theory states that classroom environment mechanisms—instructions, support, goal structures, expectations, feedback, and consequences—influence students' achievement emotions (*link 4*). This dissertation promotes this theory by indicating that special education support in general classrooms is negatively related to the unpleasant achievement emotions of adolescents receiving and not receiving special education support (*link 4.1*), while special education support in self-contained classrooms is positively related to the pleasant achievement emotions of adolescents receiving such support (*link 4.2*).

9.1 Contribution to the field of special education

This study contributes to the theory of special education in the perspective of achievement emotions. Although the push for inclusion continues to grow (UNESCO, 2017), this study indicates that students receiving special education support in self-contained classrooms might experience pleasant achievement emotions, while those receiving and not receiving special education support in inclusive classrooms might experience unpleasant achievement emotions. These findings contribute to the idea of disadvantages and advantages of serving students in inclusive and self-contained classrooms. Table 14 shows the ideas supported by the study in red.

Table 14. The advantages and disadvantages supported in the present study.

Self-contained classrooms	**Inclusive classrooms**	
Receiving SEdS	**Receiving SEdS**	**Receiving no SEdS**
Disadvantage: Less social contacts with peers receiving no SEdS	**Advantage:** More social contacts with peers receiving no SEdS	**Advantage:** More social contacts with peers receiving SEdS
Advantage: Comparison with lower-performing peers	**Disadvantage:** Comparison with higher-performing peers	
Advantage: Teacher support and instruction	**Disadvantage:** Receiving no teacher support	**Disadvantage:** Receiving no teacher support and decreased learning demands

Note. SEdS = special education support

First, these findings emphasize the advantage that students receiving special education support in self-contained classrooms can compare themselves to low-performing classmates, which according to the BFLPE, may cause positive affective outcomes (Marsh et al., 2008; Ruijs & Peetsma, 2009). These findings also support the notion that students receiving special education support in self-contained classrooms might receive more personal and higher-quality support and instruction (Dixon, 2005; Ruijs & Peetsma, 2009). According to the control value theory, these two mechanisms might indeed be related to pleasant achievement emotions (Pekrun, 2006; Pekrun et al., 2019).

In turn, these findings are not consistent with the notions that those receiving special education support in self-contained classrooms can be negatively labeled and stigmatized and that they have fewer social contacts and friendships (Dixon, 2005; Hornby, 2015). The reason might be that these disadvantages are associated with social emotions, such as loneliness, rather than achievement emotions (Wiener & Tardif, 2004). Thus, future studies could investigate whether serving students in self-contained or general classrooms is associated with students' social emotions.

In turn, this study indicates that those receiving special education support in inclusive classrooms experience unpleasant achievement emotions. Hence, this study contributes to the idea that students receiving special education support in general classrooms might lead to experiencing negative outcomes because of BFLPE (Marsh et al., 2008; Ruijs & Peetsma, 2009) and not getting enough teachers aid, as teachers are simultaneously supporting those with and without special needs (Dixon, 2005; Ruijs & Peetsma, 2009). As mentioned, these BFLPE and supportive mechanisms might be behind these unpleasant achievement emotions (Pekrun, 2006) and should be considered when inclusion is implemented.

This study also suggests that even those receiving no special education support experience unpleasant achievement emotions in inclusive classrooms. Hence, this study contributes the idea that those receiving no special education support did not receive enough aid and learning demands in inclusive classrooms (Dixon, 2005; Ruijs et al., 2010).

Although the aim in inclusive education is to support all learners in inclusive classrooms (OECD, 2017), this study suggests that this is not necessarily accomplished in a way that would support positive achievement emotions. Furthermore, in inclusion, it is considered to be a basic human right of all students to be educated alongside their peers in inclusive classrooms (Hornby, 2015; OECD, 2017), and students receiving and not receiving special education support might have more social contact and friendships with each other (Dixon, 2005; Hornby, 2015; Ruijs & Peetsma, 2009). Therefore, this study suggests that inclusion should be one of the key options in special education, but these disadvantages regarding adolescents' emotions and related mechanisms must be considered when inclusion is implemented.

10 Limitations and methodological recommendations

This study has many strengths but also several limitations that must be considered when interpreting the results and planning future research. Next, the summary of limitations and methodological recommendations are presented. Some of these issues have also been addressed in the articles.

10.1 Sample

Notably, the overall study sample was large, and different sampling methods were used to obtain a geographically representative sample. However, the present work observed EFs and mathematics-related achievement emotions among Finnish eighth graders, which may limit the generalizability of the findings to different cultures and age groups. Notably, in the Finnish school system, the 8th grade is in the middle stage in the lower secondary school (7th to 9th grades). Hence, these graders may experience future education more distantly than 9th graders and this may affect the results obtained, such as emotions in mathematics (Pekrun, 2006). In the future, researchers should explore emotions and EFs in different class degrees and in different cultural contexts.

Studies I and II investigated EFs and mathematics-related achievement emotions among adolescents with mathematics difficulties, low mathematics performance, and average or higher mathematics scores. However, the sample in study I consisted exclusively of Finnish eighth graders with low and average mathematics grades, as the focus was on those with mathematics difficulties, while study II focused on the overall eighth-grade sample. Hence, particularly the groups with average or higher mathematics scores differed in studies I and II and should be considered when interpreting the results.

Moreover, students receiving special education support in self-contained and general classrooms comprise challenging study groups due to modest sample size issues. However, the samples corresponded well to the actual occurrences (Statistics Finland, 2011). Because of the modest sample sizes, small effects regarding students receiving special education support in self-contained and general classrooms might not be significant. However, achievement emotions in general classrooms were investigated using multilevel models that considered the nested data structure and controlled for measurement and sampling errors.

However, in the future, it would be worth considering whether it makes statistical sense to use a non-random sample when studying students receiving special education support, for example, selecting all students receiving special education support (the whole reference population—census; Martınez-Mesa, Gonzalez-Chica, Duquia, Bonamigo, & Bastos, 2016). However, a random sample of schools and their classes is essential because it is also representative to include students receiving no special education support and non-inclusive classrooms.

10.2 Measures

The other strength of this study is that it applied widely used and reliable assessments (see Section 5.2) to measure students' mathematics performance (KTLT), behavioral EFs (ATTEX), and mathematics-related achievement emotions (AEQ-M). In addition, study III used latent AEQ-M and KTLT constructs to account for measurement errors. As presented in the original article, structural equation modelling techniques showed that these latent constructs were reliable and fit the data well. However, some measure limitations should be considered.

First, only one measure was used to measure different study components. Specifically, only the self-report AEQ-M was used to assess adolescents' mathematics-related achievement emotions. However, the AEQ-M based on large theory of achievement emotions (Pekrun, 2006), has shown good internal reliability in this and other studies (Pekrun et al., 2019; Sakiz et al., 2012), and it is easy to implement in students' learning context for a large sample. To understand achievement emotions widely, future studies could use other measures for analyzing students' achievement emotions, such as physiological measurement (Kassam & Mendes, 2013) or analyzing students' emotional expressions (Else-Quest, Hyde, & Hejmadi, 2008).

In addition, ATTEX, a teacher rating scale, was only used to measure adolescents' behavioral EFs. Furthermore, the risk of using teacher rating scales is that factors other than students' behaviors may influence teachers' evaluations. However, this study found that teachers did not evaluate all students with mathematics difficulties as having EF problems such as hyperactivity and impulsivity problems. Furthermore, the ATTEX determines EFs comprehensively, evaluated EFs in relation adolescents' classroom context, demonstrated good internal reliability in this study, and good internal reliability and criterion validity in the previous study (Klenberg et al., 2010). Teacher assessments are shown to be more reliable for evaluating students' behavioral EF problems than self-reports (Du et al., 2008). However, to obtain a comprehensive picture of EFs, future studies could combine the use other EF measures, such as self-reported rating scales (McGlaughlin et al., 2005), teacher-rating scales (Klenberg et al., 2010), and cognitive tests (Clark et al., 2010).

Finally, only the KTLT was used in this study to determine mathematics performance. However, the standardized KTLT is widely used in Finland, showed good reliability in this and previous studies (e.g., Korhonen et al., 2014; Kyttälä, 2008) and good criterion validity in a previous study (Räsänen & Leino, 2005). Furthermore, this study operationalized mathematics performance broadly and did not distinguish between different mathematics skills (e.g. problem solving and algebra). However, the standardized mathematics test used in this study was designed to screen mathematical difficulties in general instead of specific skills (Räsänen & Leino, 2005) and is reliable and widely used for this purpose in Finland (e.g., Kyttälä, 2008). Future studies could investigate whether students' problems with specific mathematics skills were associated differently with behavioral EFs (see Kroesbergen et al., 2003) or emotions.

Notably, this study measured EFs, mathematics-related achievement emotions, and special education support in mathematics. Although previous studies suggested EFs and emotions should be considered mainly in mathematics (Bull & Lee, 2014; Geary, 2004; Pekrun et al., 2017), future research should examine these components in relation to other subjects as well.

10.3 Study groups

The selection and characteristics of the study groups includes issues that are important to consider. First, the use of cutoff scores on the mathematics test to determine mathematics performance groups should be considered critically; individuals classified near the cutoff point might be misclassified. However, follow-up analyses indicated that the results did not differ when students near the cutoff score were eliminated from the analyses.

Furthermore, the use of one standardized measure of mathematics performance as a criterion for mathematics difficulties could well be criticized. However, this study used cutoff percentiles widely used in previous research to define mathematics performance groups (e.g., Mazzocco & Devlin, 2008; Wu et al., 2014). Additionally, it might be that the mathematics difficulties group in Finland does not correspond to those in other countries because Finnish students tend to perform highly on international comparisons (OECD, 2004; OECD, 2019). However, the lower cutoff percentile was used in this study to identify the group with mathematics difficulties than that used in other Finnish studies using the KTLT (Kyttälä, 2008).

As this study found that mainly adolescents with mathematics difficulties had behavioral EF problems and showed shame in mathematics, as well as that there were gender variations in emotions among mathematics performance groups, correlational analyses would not show these results. Future research could use several measures of mathematics performance to determine mathematics difficulties.

The results of the gender differences in emotions may be due to the tendencies and willingness of to report different emotions rather than differences in the frequency of emotional experiences. The social acceptability of different emotions (Brody, 2000) or the stereotype that females feel emotions more intensely than males (Grossman & Wood, 1993) might have influenced this willingness. Anger and pride might be acceptable for males and shame might be acceptable for females (Brody, 2000). However, the direction and magnitude of gender differences in emotions varied according to the three mathematics performance groups. The additional analysis also showed that there was only a marginally significant difference in pride between females with mathematics difficulties and males with low mathematics performance. Thus, it is impossible to explain the results only on the basis that females and males have a willingness to admit experiencing specific emotions.

Because students in Finland receive support according to special education support needs in mathematics rather than diagnosis-based needs (FNBE, 2004, 2016), this study did not have comprehensive diagnostic information. However, this study also revealed that adolescents' mathematics performance was at a low level on average if they received special education support in mathematics. Additionally, this study did not differentiate between part-time and full-time SEdS in general classrooms. However, groups receiving part-time and full-time SEdS in general classrooms did not differ significantly in mathematics-related achievement emotions, and both groups reported negative achievement emotions (presented in the original article, study III).

Furthermore, as students were not randomly divided between general and self-contained classrooms, students with severe difficulties could be placed in self-contained classrooms. Although we controlled for mathematics performance, differences in metacognition and self-awareness might affect reported achievement emotions. However, teachers reported that adolescents receiving special education support understood the questionnaire. Indeed, the AEQ-M showed strong measurement invariance across the special education groups; these groups seemed to understand the AEQ-M similarly. Furthermore, adolescents receiving mathematics special education support in self-contained classrooms were from general schools and might be integrated into general classrooms in other subjects. Thus, the variation in background characteristics, such as cognitive abilities between students in self-contained versus general classrooms, might be negligible.

10.4 Implementation

Methodological recommendations and limitations regarding the implementation of the research should also be considered. First, it should be noted that this study was cross-sectional, hence making a definitive causal conclusion about the relationship is impossible. In the future, longitudinal and experimental studies will be needed to investigate causal relationships.

Although the present study investigated theoretically critical components—EFs and emotions—among adolescents struggling with mathematics and receiving special education support, some key factors may have been omitted from the study. The control-value theory states that the control and value appraisals are the antecedents of achievement emotions (Pekrun, 2006), and these appraisals have been found to predict achievement emotions (e.g., Henschel & Roick, 2017). Hence, future studies should investigate whether the results of the present study hold when controlling for these two appraisals.

Furthermore, to understand the cognitive and behavioral level of EFs among students with mathematics difficulties, studies that investigate behavioral and cognitive EFs among such students simultaneously might be needed. Generally, future studies could investigate together affective, social, and cognitive variables among students struggling with mathematics and receiving special education support. In addition, classroom mechanisms, such as the BFLPE, might be worth considering (Kocaj et al., 2018).

Future studies could also investigate whether the proportion of students receiving special education support in general classrooms has contextual effects on several affective and social outcomes among students receiving no special education support. In such studies, mechanisms that can explain the classroom-level effects, such as changes in learning demands (Litvack et al., 2011), could be considered. However, if more variables are added to the models, especially multilevel models, the sample size must also be increased so that models are not too complex in relation to the sample size (Muthén, 2008).

11 Practical implications

This present study provides valuable insights for meeting and supporting behavioral EF problems and achievement emotions in general and self-contained classrooms. Notably, some of these insights are presented in the original articles.

11.1 Regarding executive functions

First, this study suggests that adolescents with mathematical difficulties who exhibit behavioral EF problems should be comprehensively supported in mathematics classrooms. Even though teachers might perceive that it is primarily males who have behavioral problems, the present study suggests that support for overcoming EF problems should cover females with mathematics difficulties, as they also exhibit several behavioral EF problems.

Specifically, females and males with mathematics difficulties might learn to cope with different EF problems, such as initiative, shifting attention, and planning problems if teachers direct students to follow steps and instructions, such as to start tasks, plan activities, set goals, and shift attention in mathematical problem solving and learning (strategic instruction; Mooney, Ryan, Uhing, Reid, & Epstein, 2005; Naglieri & Gottling, 1997; Ylvisaker & Feeney, 2008). Females and males with mathematics difficulties might also learn to cope with different EF problems, such as initiative and distractibility problems, if they self-monitor, record, and control such behaviors and are rewarded for controlling them (self-monitoring; Mooney et al., 2005). The future studies could explore whether these practical methods support the behavioral EF problems of adolescents with mathematics difficulties in their classrooms.

According to the theoretical model (Geary, 2004), this support might help student's mathematics learning and reduce their difficulties with mathematics. Individuals with mathematics difficulties perceived that they need more help to cope with their EF problems, and this help could enable them to perform better in mathematics (Desoete, 2009). However, the present work also implies that adolescents with hyperactivity and impulsivity problems did not necessarily have mathematics difficulties, although these adolescents might often take up teachers' attention.

11.2 Regarding emotions

In addition to EF problems, the present study suggests that mathematics-related achievement emotions among adolescents with mathematics difficulties and low mathematics performance should be supported. However, this support could be slightly different for females and males. Specifically, females with mathematics difficulties and males with low mathematics performance primarily need emotional support, particularly the former, to enhance their pride and enjoyment and prevent their hopelessness.

The control-value theory determined that students might experience more pride and less hopelessness if they perceive that they can succeed in mathematics, as well as more enjoyment if mathematics activities are valuable and controllable (Pekrun, 2006). Hence, positive feedback, success experiences, and valuable and interesting activities for females with mathematics difficulties might decrease their feelings of hopelessness and increase their pride and enjoyment. Previous findings indicated that teachers' emotional support, such as encouragement and respect, might prevent students' hopelessness and increase enjoyment (Sakiz et al., 2012).

In turn, males with low mathematics performance and with mathematics difficulties might need emotional support primarily for their anger, anxiety, and hopelessness. Hence, males struggling with mathematics also need to experience mathematics success and positive feedback to decrease their anxiety and hopelessness. The control-value theory states that anger might relate to failure that is caused by things outside of one's control and by valueless mathematics activities (Pekrun, 2006). Hence, to prevent anger, males struggling with mathematics might need valuable mathematics activities and experiences that demonstrate how their effort rather than external aspects leads to their success. Furthermore, when teachers emphasize individual progress rather than competition in the classroom, students' anger and anxiety might reduce (Baudoin & Galand, 2017).

In addition, this study indicated that females and males with mathematics difficulties reported shame in mathematics. The control-value theory sates that students might experience shame if they perceive that they have caused their own failure (Pekrun, 2006). Hence, both females and males with mathematics difficulties need more facilitated mathematics tasks that they can solve by themselves. It is also suggested that recognizing the feelings of shame and evaluating the causes of shame in positive terms may reduce students' shame (Oades-Sese et al., 2014). Encouraging words (e.g., you are good) from teachers, positive feedback, and individualized instruction can decrease students' shame (Oades-Sese et al., 2014). Future research should examine whether the suggested practical solutions support achievement emotions of adolescents struggling with mathematics.

Notably, supporting mathematics-related achievement emotions might even prevent students' low mathematics performance and difficulties (Carey et al., 2016; Pekrun, 2006; Pekrun et al., 2017; Putwain et al., 2018). However, this study also revealed that boredom was not a key emotion among adolescents with mathematics difficulties and even those without mathematics difficulties might report boredom.

11.3 Regarding special education support

In contrast to the current policies, the present study suggested that inclusive settings might increase the unpleasant achievement emotions among adolescents receiving and not receiving special education support. This present work suggested that placing students receiving special education support in small self-contained classrooms increased their pleasant achievement emotions more than placing them in more inclusive general classrooms.

Hence, in light of the present findings, educators could consider supporting the achievement emotions of adolescents receiving special education support in small self-contained classrooms where more personal and individualized support is available. However, as the global aim is to support students in inclusive general classrooms (UNESCO, 2009b, 2017), the present study suggests that policy makers and educators should develop practical solutions that support the achievement emotions of adolescents in more inclusive classrooms.

As stated earlier, comparisons with higher performing classmates (BFLPE; Pekrun et al., 2019) are one critical issue that might cause adolescents struggling with mathematics and/or receiving special education support to experience unpleasant emotions in inclusive classrooms. Hence, to reduce the BFLPE, teachers could give individualized feedback and instruction to adolescents in inclusive classrooms, thus increasing their enjoyment and pride and decreasing their hopelessness, shame, anger, and anxiety (Pekrun et al., 2019; Roy, Guay, & Valois, 2015).

Additional support, such as coteaching and assistance, could be used to support the emotions of students receiving special education support in inclusive classrooms, because increased personal and emotional support is related to pleasant achievement emotions (Sakiz et al., 2012). This additional support might give teachers more time to help students receiving no special education support in inclusive classrooms so they can experience less anxiety and hopelessness (Ahmed et al., 2010; Sakiz et al., 2012).

Furthermore, differentiated and varied instruction that matches students' abilities may allow all students receiving and not receiving special education support to experience appropriate challenges in inclusive classrooms (Lawrence-Brown, 2004), thus decreasing their boredom, hopelessness, and anxiety (Pekrun, 2006). Future research should examine whether the suggested practical solutions support students' achievement emotions in inclusive classrooms

Notably, the present work suggests boredom is a critical emotion to consider in inclusive classrooms among adolescents receiving and not receiving special education support even though the present study also revealed that boredom was unrelated to mathematics difficulties.

11.4 Conclusion

In conclusion, this study suggested that educators and policymakers should comprehensively consider the emotions of adolescents when they strive for inclusion and implement the three tiers of support in more inclusive settings (FNBE, 2004, 2016). This study also suggested that educators should comprehensively consider the EF problems of adolescents with mathematics difficulties in the classroom context.

This consideration is necessary, as unpleasant achievement emotions and EF problems might even deepen students' mathematics difficulties and lower their mathematics performance, leading to the risk of dropping out (Fitzpatrick et al., 2015; Geary, 2004; Hakkarainen et al., 2015; Respondek et al., 2017; Pekrun, 2017). However, teachers might need more resources and training to implement inclusion and to support the achievement emotions and EFs of adolescents in general mathematics classrooms (Gilmore & Cragg, 2014; UNESCO, 2009b).

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